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PATRON: HIS MAJESTY THE KING.

Vol. IX, Part I.

1922 - 1923.

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THE JOURNAL

OF

THE ROYAL SOCIETY

OF

WESTERN AUSTRALIA.

VOL. IX., PART I.

PROCEEDINGS OF THE ROYAL SOCIETY OF WESTERN AUSTRALIA.

(*For Half-year ending 31st December,* 1922.)

11*th July,* 1922.—The President, Mr. F. E. Allum, in the Chair. The annual report of the Council was read and adopted, and officers elected for the ensuing year. In accordance with the alteration in the Rules two Hon. Secretaries were elected, one for Physical Science (including Chemistry, Engineering, and Mathematics), and one for Natural Science. The general secretarial duties, which had been kindly undertaken by Mr. L. Glauert, F.G.S., since the resignation or Mr. D. A. Herbert in December, 1921, were divided between the two secretaries according to mutual agreement, but subject to the approval of the Council.

Mr. Glauert exhibited (a) two minute Crustaceans—*Nannastacus zimmeri,* Calman, and *Iais pubescens*—collected off piles at Fremantle, and now recorded from Western Australia for the first time, (b) a new species of swamp tortoise—*Chelodina millymillyensis*—from Milly Milly Station, Murchison River (Contributions to the Fauna of W.A., No. II.), (c) some aboriginal mining tools from the ochre mines at Wilgie Mia, Weld Range. Professor Nicholls, in a short address on Australian frogs, dealt with a series of burrowing frogs collected by Mr. Glauert during a visit to the Murchison.

8*th August,* 1922.—The President, Mr. E. de C. Clarke, in the Chair. An address entitled "The Structure of the Sidereal Universe" was delivered by Dr. Robert J. Trumpler, Ph.D., Assistant Astronomer, Lick Observatory. Dr. Trumpler outlined recent re-

searches in connection with the determination of stellar distance, and explained the most modern theory regarding the structure of the stellar system. The address was illustrated throughout by numerous lantern slides and diagrams.

17*th August*, 1922.—Special meeting held to welcome the members of the Wallal Solar Eclipse Expedition. The President, Mr. E. de C. Clarke, occupied the Chair, and about 140 members and friends were present. The guests included Dr. W. W. Campbell (leader of the Lick Observatory party), Mrs. Campbell, Dr. J. H. Moore, Dr. R. J. Trumpler, Dr. and Mrs. Adams, Prof. A. D. Ross, Mr. J. B. O. Hosking; Prof. C. A. Chant (leader of the Canadian party), Mrs. and Miss Chant, and Dr. R. K. Young; Mr. J. Hargreaves (leader of the English party), and Mr. Clark-Maxwell; Mr. C. Nossiter (leader of the W.A. party), and Messrs. J. J. Dwyer, C. S. S. Yeates, G. M. Nunn, and V. J. Matthews. During the course of the evening short lecturettes were given by some of the visitors. Dr. Campbell spoke briefly of his observations on radial velocities of groups of stars; gaseous and planetary nebulæ were discussed by Dr. Moore; Prof. Chant described Toronto University's work and the activities of the R.A.S. of Canada; Dr. Adams dealt with recent earthquakes in the Rotorua district of New Zealand; Dr. Young, of the Astrophysical Observatory, Victoria, B.C., outlined the programme of investigation ahead of his institution. After Mr. A. Montgomery had thanked the visitors for their speeches, supper was served.

12*th September*, 1922.—The President, Mr. E. de C. Clarke, in the Chair. Mr. Farquharson, M.A., M.Sc., read a paper on "Some Additions to the Knowledge of the Geology of Kalgoorlie, with special reference to the occurrence of Porphyritic Olivine Picrite." A paper, "Contributions to the Flora of W.A., No. 1," describing four new species of flowering plants from the Avon district, was read by Mr. C. A. Gardner. Mr. Shelton communicated a paper by Mr. J. Clark on the structure and habits of *Enasiba mirocera*, a new species of myrmecophilous beetle. Reports on the excursion, Darlington to Greenmount, were read by Messrs. E. de C. Clarke and C. A. Gardner. Mr. J. Clark furnished a most interesting exhibit of honey ants—*Camponotus inflatus*—obtained from the Murchison district. This is the first recorded appearance of these insects in Western Australia. Mr. Gardiner exhibited preserved specimens of plants procured on the recent excursion. Mr. Glauert exhibited (a) *Terebratulina cancellata*—a rare brachiopod taken alive at the beach, (b) local barnacles (some probably new), including *Lepas pectinata* and *Lepas hillii* (var.), (c) Isopods collected from *Cymodocea*, (d) fresh water shells—probably *Isidora australis*, Kuster.—from the locality of the Milly Milly Station.

10th October, 1922.—The President, Mr. E. de C. Clarke, in the Chair. Dr. Donald Smith, M.B., Ch. M., gave an address entitled "X-Rays in Medicine." The address was effectively illustrated by a unique collection of lantern slides depicting X-ray photographs. Mr. A. Montgomery exhibited jarrah leaves, from King's Park, attacked by some insect or fungal pest. Mr. H. Steedman exhibited (a) a specimen of gum leaves thickly infested with insect galls, (b) a species of perennial sweet pea. Reports on the excursions to Mundaring Weir and from Hovea to Swan View were submitted by Prof. Nicholls and Dr. Simpson respectively.

14th November, 1922.—The President, Mr. E. de C. Clarke, in the Chair. Prof. A. D. Ross, D.Sc., F.R.S.E., read a paper on the scientific investigations at Wallal in connection with the recent solar eclipse. The method employed in order to determine the "Einstein effect" was explained in detail, and apparatus was exhibited whereby the total light of the corona, and also the distribution of light intensity in the corona, could be measured.

12th December, 1922.—The President, Mr. E. de C. Clarke, in the Chair. In accordance with the resolution of the Council the motion was submitted to the meeting "that after June 30th, 1923, the annual subscription for ordinary members be £1 11s. 6d., and for associate members 15s." After discussion it was decided to defer consideration of this matter until the May, 1923, meeting. Mr. L. Glauert, F.G.S., read papers on (a) *Cidaris comptoni,* sp. nov., a Cretaceous echinid from Gingin, (b) Contributions to the Fauna of W.A., No. III., (c) an annotated list of lizards from Wallal, and also communicated a paper by Dr. R. J. Tillyard on the *Embioptera,* or web-spinners of W.A. Mr. C. A. Gardner read his "Contributions to the Flora of W.A., No. II.," dealing with eight new species of W.A. plants, and Mrs. T. Pelloe described a visit to the Stirling Ranges, and enumerated many of the plants, animals and insects noted on the way. Mr. Glauert exhibited (a) a living tortoise from the Murchison River, (b) several species of barnacles new to the Museum collection.

AN OCCURRENCE OF IMPSONITE IN WESTERN AUSTRALIA.

By

R. A. Farquharson, M.A. (Oxon.), M.Sc., F.G.S.

(Read: 9th May, 1922.)

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I.—INTRODUCTION.

At the end of June, 1920, a sample was received at the Geological Survey Office, Perth, from Mr. Hobler, Engineer for Commonwealth Railways, who stated that it had been handed to him while he was accompanying the Ministerial party in Kimberley.

On the same day an identical sample was received through the Honourable Mr. Colebatch, who in a covering letter stated that it had been given to him by a Mr. Walter Oakes, of Ningbing Station, Wyndham, and that Mr. Oakes believed it to be oil shale or coal. There is no doubt that both this sample and that of Mr. Hobler came from the same spot, viz., the one discovered by Mr. Oakes.

Some time later, about 29th September, another sample of the same material was received from Mr. M. P. Durack, who said that he had obtained it from a locality close to Oakes' Find, near the junction of the Ord and Negri Rivers, East Kimberley.

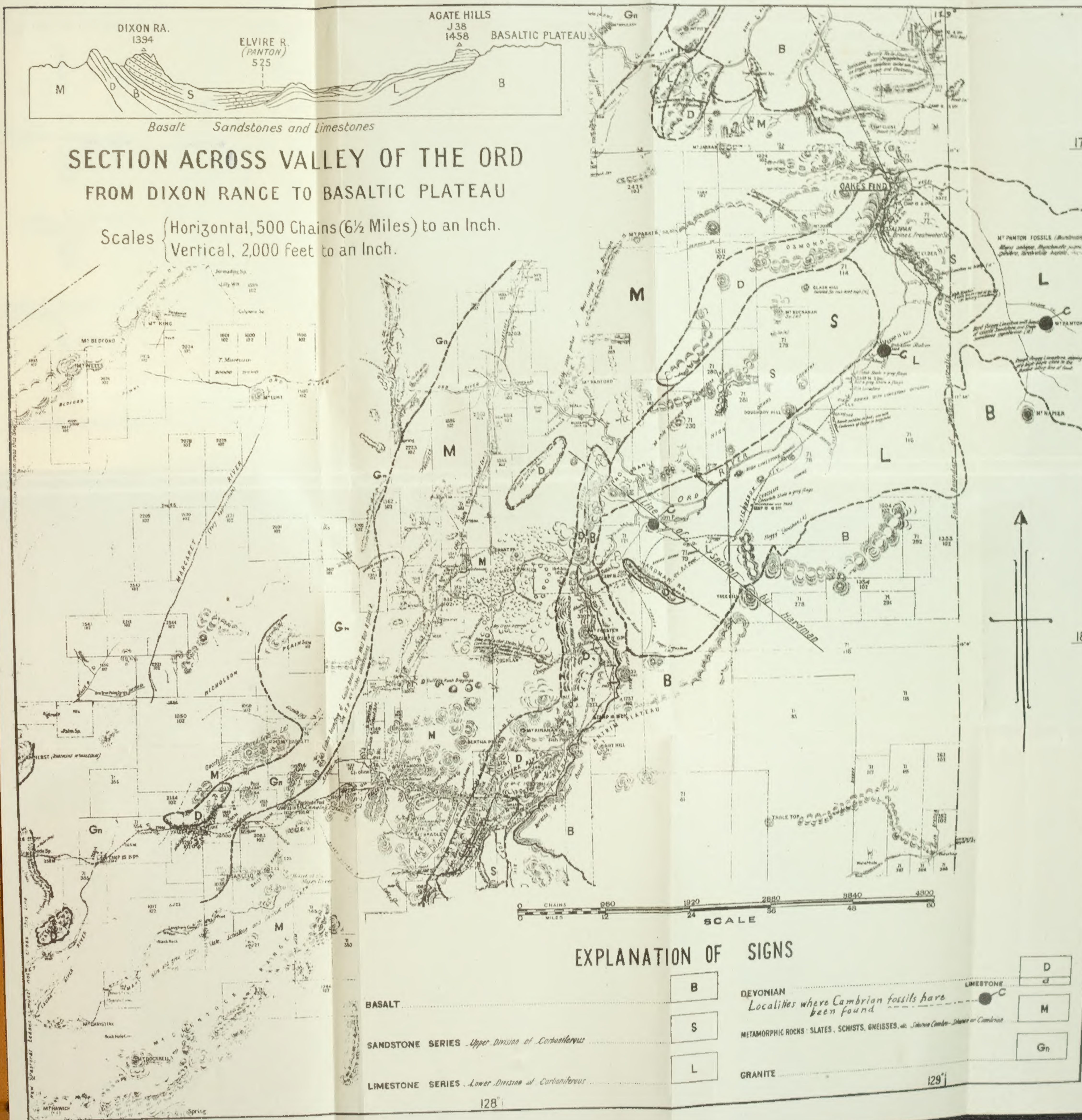
As an examination of all the specimens showed that the material was of sufficient importance to warrant further investigation, Mr. Blatchford, who was at the time in West Kimberley, was instructed to inspect the area in which the finds were made. He not only confirmed the discovery of the material by Mr. Oakes at the junction of the Ord and Negri Rivers, but found that years previously it had been handled unknowingly by man in a well, near Texas Homestead, on the bank of the Ord River, some five miles up from the junction with the Negri, and he concluded, therefore, that in all probability the material occurred at least at intervals throughout these five miles. The location of the finds is marked on the accompanying plan. (Plate I.)

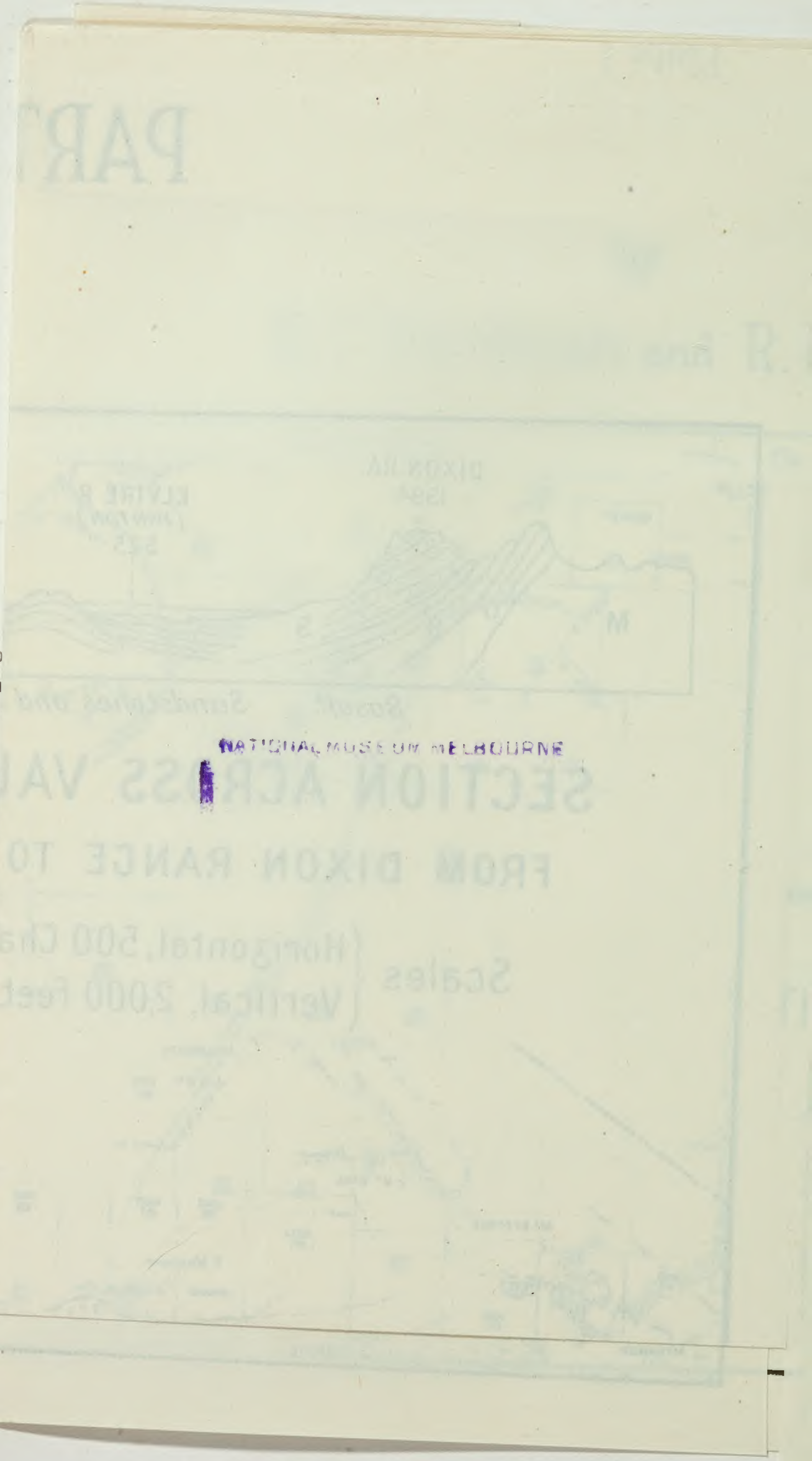
Plate I.

GEOLOGICAL MAP OF PART OF EAST KIMBERLEY DISTRICT

by

E. T. Hardman and R. L. Jack





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II.—NATURE OF THE MATERIAL.

All the samples sent in are identical. They consist of a black mineral with a brilliant lustre, which is very brittle, combustible and mostly seamed with cracks. At first sight, it rather closely resembles anthracite coal, but an investigation of its physical and chemical characters proves that it is not a variety of coal, but an asphaltum. Through the courtesy of Dr. Simpson I am able to give the following more important physical and chemical characters of the mineral: -It ignites and burns freely, and does not melt on heating even above 300 deg. C, decomposition taking place without any signs of softening. Specially selected clean fragments had a density of 1.154, but many fragments had densities rising from this figure to 1.20, owing to adhering small quantities of calcite and rock. The calorific value of the purest material was 16573 B.T.U. Ultimate analysis of Mr. M. P. Durack's specimen gave:—

	per cent.
C	89·40
H	7·26
S	·68
N	·41
O	2·25
	100·00
Ash	·43

Proximate analysis gave:—

	Per cent.
Moisture	0·37
Volatile	41·54
Fixed Carbon	56·27
Ash	1·82*
	100·00

Moderately low temperature distillation showed the volatile matter to consist of:—

	per cent.
Water	1·74
Oil	19·89
Gas	19·91
	41·54 (as in the proximate analysis).

Analysis of original impsonite from Indian Territory, U.S.A. (reference later):—

	per cent.
C	86·57
H	7·26
S	1·38
N	1·48
O	2·00
	98·69
Ash	1·31

* The proximate analysis was made on a different lot of fragments from those used in the ultimate analysis. Hence the slight difference in results of determination of the ash.

The gas burnt freely with a slightly luminous flame. The oil had a density of 0.758 at 25 deg. C., it was dark-brown in colour, translucent, fluorescent and of low viscosity. The water which distilled over was distinctly acid in reaction.

Digestion of the asphaltum with carbon bisulphide in the cold extracted a bright black bitumen, amounting to 15.38 per cent. of the whole in the case of Mr. Durack's sample.

Comparison of these characters with those of similar minerals from America, shows beyond doubt that the mineral is a solid asphaltite that can be included under the term "Glance Pitch," or "Manjak," used as a group name. It most closely agrees with the variety Impsonite, first described over twenty years ago from East Indian Territory, U.S.A.*

The importance of the asphaltites and closely related substances lies in the fact that they are indications of the past or present existence of petroleum in the neighbourhood in which they are found. They are produced by the drying or inspissation of petroleum, *i.e.*, as the residual products of natural distillation in which the more volatile fluids have been scattered, the heavier oil and sulphur compounds concentrated and some degree of polymerisation has taken place. Between oil and asphalt, there are all stages ranging from the liquid to the solid state, the differences between the stages being largely due to differences in composition of the original oil and to differences in the degree of drying. The comparative hardness and the extent to which chemical alteration has taken place in the mineral from Oakes' Find prove that it is of considerable geological age.

III.—MODE OF OCCURRENCE OF THE MINERAL.

The amount of knowledge at hand up to the present about the occurrence of the mineral is small, consisting only of what may be deduced from a study of the geological maps of the Kimberley Division, prepared many years ago by Mr. E. T. Hardman, and at a later date by Dr. Jack, from the consideration of a few other published reports on some aspect of the geology of the Ord River District, and of the facts that may be ascertained by an investigation of the material in which the mineral is found. The information that may be derived from the maps, sections, and other published reports, will be considered later.

The material in which the impsonite occurs is a fine textured rock, which in hand specimens ranges in colour from dark-green when nearly fresh, through dull grayish-green to brownish-yellow, the colour depending on the degree of alteration. There are at least

* An albertite-like asphalt in the Choctaw Nation, Indian Territory, U.S.A., by Joseph A. Taff: Am. Journ. Sci, Sept., 1898, 4th Series, Vol. VIII., p. 224.

two varieties of it, one massive or showing only slight signs of fracturing, the other so fractured as to be virtually a breccia and consisting of fragments of comparatively fresh rock separated by more decomposed and broken down material. It may be asserted that the fracturing is due to the amount of blasting that has been necessary to get the specimens, but the appearance of the surfaces, the shear planes and the cracks as well as the occurrence of the mineral along these cracks and planes shows clearly that this cannot be the case. In some specimens, the massive variety shows a clean-cut junction with a sheared rock, and along the surfaces of separation, are well-marked slickensides. In others, the massive variety is more cracked and disintegrated than sheared.

The outstanding features of the rock are its extremely vesicular character and the fact that quite a number of vesicles are filled with impsonite. The vesicles range in size from that of a pin-head to that of a walnut. Some are spherical, others elliptical, and others again are almost disc-shaped. The material filling them is different in different vesiles and consists:—

(a) of calcite, which fills the largest.

(b) of dull greenish chlorite, or of calcite and a border of greenish chlorite.

(c) of quartz in shot-like form.

(d) of impsonite.

(e) of impsonite and calcite with or without pyrites, the calcite being in some partly bordered by the black mineral, in others surrounding the black mineral, and in others occurring along numerous cracks in it.

Some of the vesicles are only partly filled, others are quite empty.

The sheared or partly brecciated rock is by no means so noticeably vesicular as the massive, though in the comparatively fresh fragments in it a few small vesicles can be made out. On the other hand, this fractured rock is much more heavily impregnated with impsonite than the massive rock, the mineral occurring not in holes as in the latter but in large and small patches and strings.

Owing to the fineness of texture of the rock, the extent to which the green chlorite binds the felspar laths of the rock-mass, and to the fact that though the vesicles are in places fairly numerous they are not connected with one another, the effective pore space of the rock and consequently its capacity for taking up and storing fluids is small except where shearing is pronounced.

Nevertheless, the effective porosity of the greenish somewhat decomposed but massive rock, determined by the method of alternately heating and cooling the water in which it is immersed for a

period of four or five days, is appreciable, amounting to 3.43 per cent. According to E. R. Buckley* the effective porosities of various building stones (determined by the same method) are as follows:—

		Limits.	Average effective porosity.
14 samples of granite	..	0.108 to 0.519	0.332
11 samples of limestone	..	0.53 to 13.36	4.43
16 samples of sandstone	..	4.81 to 28.28	14.46

The effective porosity, therefore, of the somewhat decomposed rock compares favourably with the average for limestones, and is very considerably greater than that for granite.

The rock itself, both massive and sheared, is a vesicular basaltic dolerite. In section it consists of a loose plexus of thin twinned laths of felspar more or less clouded, between which is either a fine granular dust or greenish chlorite due to the decomposition of pre-existing augite. Small patches wholly made up of greenish chlorite occur scattered through the mass.

The impsonite occurs in the rock in a variety of ways:—

(a) in vesicles filling the whole of the cavity and with a border of chloritic material between it and the basalt (Plate II.)

(b) in vesicles with calcite, in some cases as a border to the latter but extending only round one end of an elliptical vesicle, in others occupying the interior of the hole and surrounded by calcite, in others again showing a network of cracks which are filled with calcite.

(c) in very thin strings along cracks in the more or less massive rock.

(d) in large strings and patches in the sheared rock, occurring along the cracks and shear planes and in one instance in a comparatively thick layer along a probable joint plane.

With the mineral in some of the amygdaloids is a small amount of pyrites, and this mineral is scattered in small grains through the decomposed and sheared rock.

Microscopical examination of the junction between the two varieties of rock shows the presence of a sheared zone filled with fragments of the basalt surrounded by granular quartz (the remains of a vesicle), granular felspar and granular calcite, black strings of impsonite intimately associated with the calcite and also occur-

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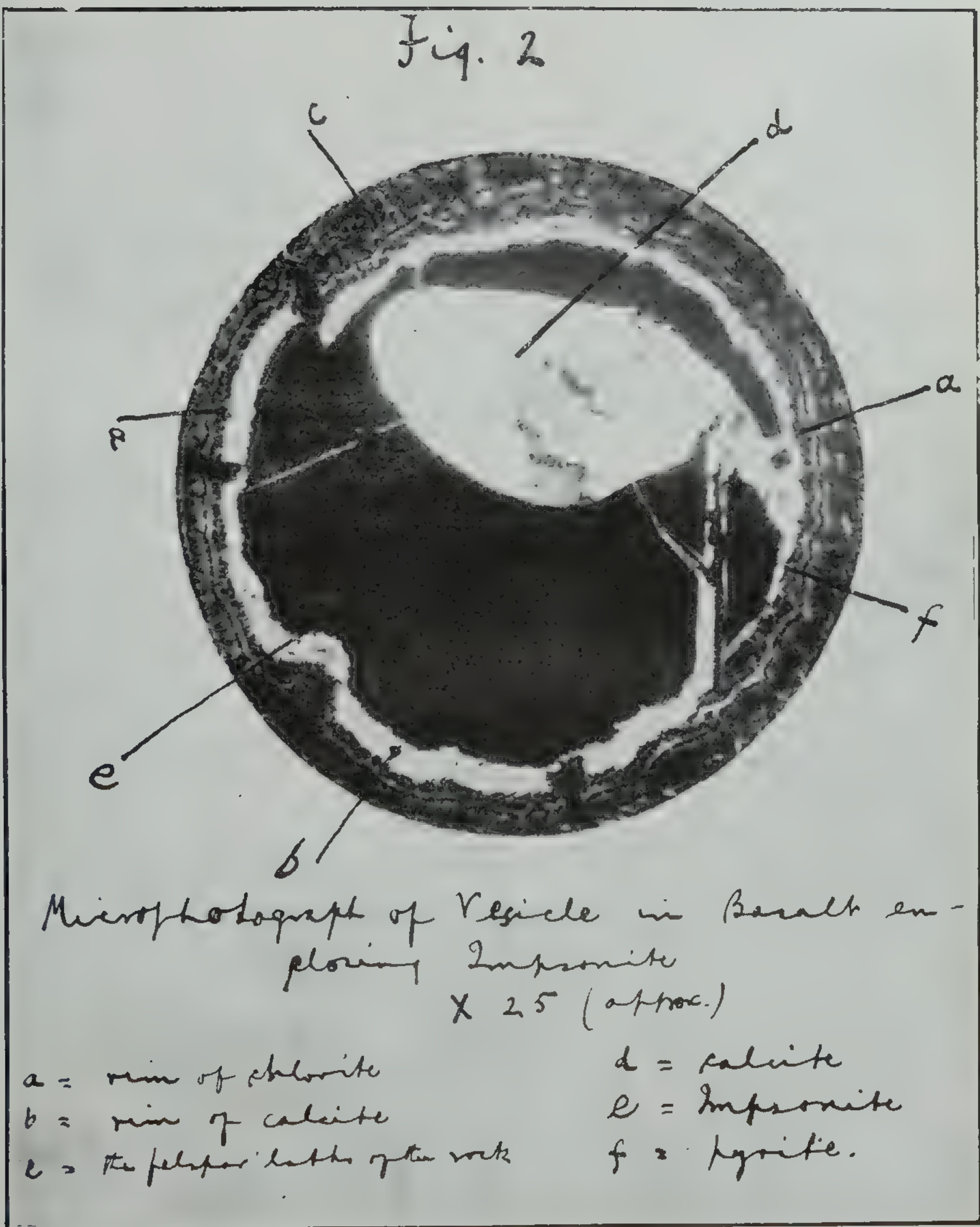
* Buckley, E. R.: "Building and Ornamental Stones of Wisconsin."

Plate II.



Impsonite in Basalt.

ring along cracks, and fragments of the rock almost black as though they had been partly impregnated with the mineral.

Sections of the black filling of the vesicles show it to be quite homogeneous, to contain no remains of any silicate or other mineral, though chlorite occurs round it and calcite both round it and through it.

The relations of the impsonite to the calcite are difficult to account for. As it occurs as a border to calcite that fills some of the vesicles, it would appear to have penetrated the rock after the formation of the calcite in the holes. On the other hand, its occurrence surrounded by calcite and also reticulated by calcite strings tends to show that the calcite was later than the black mineral. As the limestone occurs immediately above the basalt, some of the calcite fillings—especially the larger—may easily be due to carbonate solutions from the limestone which have detached the impsonite from the wall of the holes and on recrystallising have surrounded it. Another and perhaps more correct explanation is that the black mineral formerly existed in the holes in liquid form, that, as in time, some of the volatile hydracarbons evaporated, the residuum solidified in a smaller space and the holes were entered by carbonate solutions which filled up all cracks existing in the mineral, and may even have floated off the black residuum.

IV.—GEOLOGICAL POSITION.

The general geology of the locality of the find and of the surrounding district was first mapped by Hardman in 1885, and later in 1906 by Dr. Jack, whose map was naturally to a large extent based on that of Hardman. The work of these two geologists, though differing to some extent in minor details, has up till quite recently been accepted as a correct exposition of the structure and stratigraphy of the district, and even yet, though as will be shown some modification of the mapping of the limestone is necessary, the work must be accepted as remarkably accurate when account is taken of all the difficulties both men encountered. According to Hardman,* along the western side of the Ord River and extending eastward on the south side of the Negri River are two belts of rock consisting chiefly of sandstone and grits. These form the higher ground and may be seen as flat-topped tablelands. The geological age of this formation has been placed as Upper Carboniferous. Immediately underlying these sandstones and grits are fairly thick limestone beds which extend beyond the flanks of the first series, particularly to the east and south. These limestones are Lower Carboniferous. Over a great part of the country they

* Report on the Geology of the Kimberley District: E. T. Hardman, 1885, Perth, by Authority.

outcrop in bare masses, cut through by gullies and forming cliffs in which the stratification, dipping in various directions at a low angle, can be seen very distinctly. Under the limestone is a very extensive basalt sheet which extends for miles to the north, south and east (see the accompany plans and section). There is no evidence, so far as observations have gone, of contact metamorphism in the limestone, a fact which, taken in conjunction with the vesicular nature of the basalt, renders it improbable that the basalt is intrusive. Underlying the basalt are older sandstones, grits, shales, conglomerates, etc., probably of Devonian Age, which rest unconformably on still older slates, schists and gneisses possibly Lower Silurian or Upper Cambrian in Age. The stratigraphical relations of the rocks according to Hardman are shown succinctly in the accompanying section (Fig. 1).

It is clear, then, from the plans and section that according to Hardman and Jack, the limestone is Lower Carboniferous, the basalt (in which the impsonite is found) occurs as a sheet under this limestone, and that under the basalt are rocks probably of Devonian Age. It follows, therefore, that the basalt is either Upper Devonian or Lower Carboniferous in Age.

Now Hardman during the course of his explorations in 1883-1884 collected a suite of fossils from the bed of the Elvire River* to the south of Survey Station Z27 near his base line W.B.-E.B. in rocks which though without a symbol on his map must be according to the colour given them either Lower Carboniferous or Devonian, and which according to Dr. Jack's map are Lower Carboniferous. These fossils were examined by Mr. E. Etheridge, Mr. W. H. Foord and Dr. Henry Woodward, and determined as part of an Olenellus, Salterella Hardmani and numerous pteropods, *i.e.*, fossils of undoubted Cambrian age. Further, Hardman also collected fossils from the Ord River, five miles below its junction with the Elvire† opposite J.38 and at Mount Panton just east of the Western Australian border, and these also were subsequently determined as of Cambrian age.

Moreover, in 1909, Mr. H. W. B. Talbot had occasion to visit the Orde River, and from the upper stratum of limestone in a cliff near Ord River Station consisting of limestones and shales he collected a fossil which was subsequently determined as Salterella Hardmani, *i.e.*, of Cambrian age. According to Mr. Maitland‡ strata similar to those near Ord River Station extend from the Hardman Range to the Osmond Range in the north. Both Hardman and Jack have this area mapped as Carboniferous or Devonian.

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* Geology of Western Australia: Mining Handbook, by A. Gibb Maitland, Perth, by Authority.

† Geology of Western Australia: By A. Gibb-Maitland, loc. cit. This locality is virtually the same as that given for the previous find.

‡ Loc. cit

The outcrop of vesicular basalt in the bed of the river near the junction of the Ord and the Negri, Hardman's map shows correctly, and Jack's map would be accurate in this particular if the margin of the basalt were extended a little further south.

It is quite evident, therefore, that although both Hardman and Jack have mapped the limestones that extend from north of Mount Panton in a south-westerly direction along the Ord River to beyond the Hardman Range as Lower Carboniferous, these rocks cannot all be of this age. In at least three distinct localities, viz., in the bed of the Elvire River south of Survey Station Z27, at Mount Panton just east of the Western Australian border, and from the cliffs of the Ord River near Ord River Station, the limestones are from their fossil contents beyond question of Cambrian age. As according to Hardman undoubted Carboniferous limestones do occur, *e.g.*, near Mount Panton,* it follows that the limestones of the district are of two ages, Lower Carboniferous and Cambrian, and, in default of additional evidence as to their stratigraphical relations, that the former rests unconformably on the latter.

The maps of both Hardman and Jack, then, should be amended to show the occurrence of Cambrian limestones at Mount Panton and in the valley of the Ord River, though, as the actual size of the outcrop of Cambrian limestone is not known, it is not yet possible to separate the latter from the Lower Carboniferous with any approach to accuracy. In particular, Hardman's section across the valley of the Ord from Dixon Range to the Basaltic Plateau must be amended to show the presence of Cambrian limestone under the Devonian (and Silurian) and outcropping in the valley of the Ord River. It must be noted that, though these alterations are now known to be necessary, it is scarcely the fault of either Hardman or Jack that they should be so, for Hardman's report was published long before his fossils were determined, and, as Jack's investigations in the Kimberley Division were chiefly concerned with locating possible artesian water basins, he naturally assumed the accuracy of a considerable part of Hardman's results.

The important feature of the presence of both Cambrian and Lower Carboniferous limestones in the Ord River valley is the extent to which it affects the age of the impsonite-bearing basalt. Up to the present it has been accepted without question that Hardman's section across the valley of the Ord is correct, and consequently that the basalt is of Lower Carboniferous or Upper Devonian age. There is, however, now introduced the possibility of the limestone being of Cambrian age, particularly as Cambrian limestones are proved to outcrop in two localities in the valley of

* There is good reason, however, for believing that the locality labels of Hardman's fossils have been seriously mixed up, and there is at least a possibility that the limestone of the whole of the Mount Panton District and of large areas to the South-West of it is of Cambrian age.

the Ord. If this should be the case, then the basalt which occurs under the limestone, and which, owing to its strongly vesicular character, can scarcely be either a sill or a dyke, would be of Lower Cambrian age, and the outlook for the discovery of payable petroleum in the vicinity would be anything but favourable. Moreover, amygdaloidal basalts apparently similar to those at Oakes' Find occur in the Northern Territory, and according to Woolnough* they are to be regarded as of Lower Cambrian age.

On the other hand, as Hardman had with little doubt some grounds both palæontological and lithological for mapping the limestones as Lower Carboniferous,† it is probable that the limestone overlying the basalt is of this age, that the Cambrian limestone outcrops only in a few places of which the neighbourhood of Oakes' Find is not one, and that Devonian and perhaps Ordovicion fossiliferous rocks may subsequently be found between the Carboniferous and Cambrian in the district.

It will be realised, therefore, that the importance of an accurate determination of the stratigraphy of the district cannot be exaggerated, and the results of further geological work will be awaited with great interest.

V.—SIMILAR OCCURRENCES OUTSIDE THE STATE.

Up till a short time ago there was a tendency to regard this particular occurrence of impsonite as unique. The original mineral described from eastern Indian Territory, U.S.A., in 1898‡, though very similar to that at Oakes' Find, occurs as a vein in a body of greenish clay shales that are included between sandstones 100 to 150 feet apart, that are regarded as of Ordovician age and that are overlain by fossiliferous Ordovician limestone. This original mineral, therefore, occurs in a manner quite different from the impsonite at Oakes' Find.

In a Report on the Prospect of Finding Oil in South Karroo, in South Africa, Dr. A. W. Rogers mentions the fact that in the Beaufort Series, the so-called "coal" of Buffel's Kloof is a hard bright substance filling fissures, likes the "intrusive anthracite" of Laingsburg and Beaufort West Divisions. Up to the present no detailed account of the material from these localities has been found, though there is little doubt that it closely resembles the material from Oakes' Find.

Quite recently, however, there was published in the Transactions of the Geological Society of South Africa an article§ written

* Report on the Geology of the Northern Territory: Bull. Northern Territory, No. 4, p. 20, by W. G. Woolnough, D.Sc.

† See footnote regarding localities *(ante)*. ‡ Loc. cit.

§ On the Occurrence of Oil on Madrid Farm No. 281, in the Bethlehem District of the Orange Free State: by A. L. Hall, M.A., F.G.S., Trans. Geol. Soc., South Africa, Vol. XXIV., 1921, p. 98.

by Mr. A. L. Hall in which, after giving a short account of previous references to oil being found in igneous rocks in South Africa, Mr. Hall has described an occurrence of oil and oil residuum having such a striking resemblance to the one in East Kimberley that a short account of it will not be out of place.

The situation of the discovery is at Madrid Farm No. 281, about 30 miles S.S.E. of Bethlehem in the Orange Free State. The rocks of this district belong to the Stormberg Series of the Karroo System of Permo-Carboniferous age, and comprise the following in descending order:—

Basalts, amygdaloidal basalts and allied rocks.

Massive sandstones—Cave sandstone.

Soft purplish shaly sandstone.

Thin vertical basic dykes.

Resting directly on the Cave sandstone is a layer of dark volcanic rocks giving indications of oil in the form of a strong paraffin-like smell, smears of tarry matter, or small pockets of dark brown liquid bitumen (maltha).

The rock carrying the oil indications is a fine-grained nearly black basaltic variety with amygdules of quartz, zeolite, calcite, etc. In many instances a thin shell of nearly uniform width and of a compact black material surrounds the filling of the vesicles, and many vesicles are filled entirely by a black matter with no apparent zeolitic kernel. Some specimens show in a fine-grained basaltic ground-mass over 100 black vesicles which, being filled with a compact black shiny substance resembling coal, produce the impression of a rock that has caught up numerous xenoliths of this material. The larger vesicles are occupied by zeolitic or other amygdaloidal filling with a thin black shell, but nearly all the smaller vesicles are occupied wholly by the coaly-looking substance which is identical with the black shell. Not only the solid black material was found in the basalt, but actual pockets of liquid oil, and from one of the largest one gallon of oil could be siphoned off. During drilling and blasting the pockets are disturbed and their contents become spread out along joint and other divisional planes.

The basalt is of a proved maximum thickness of 42 feet on Madrid, and it is impregnated for a horizontal distance of 4,500 feet and for the whole of the thickness.

The thin vertical basic dykes are later in origin than the purplish clays, the Cave sandstone, and the basalt group.

Chemical analysis of the black constituent of the vesicles suggests that it is some hydrated silicate mineral which was partly altered with loss of crystalline structure and discoloured black by the infiltration of bituminous matter.

Mr. Hall concludes that the occurrence represents not a primary but a secondary deposit, and that the black material now filling the vesicles is not some carbonaceous substance caught up by the igneous rock, but an alteration product of the mineral which filled the vesicle prior to the impregnation of the rock by volatile hydrocarbons. The small amount of carbon still left in the altered amygdaloid is the residual base left after the removal of the volatile constituents. He further concludes that the impregnation of the basalt took place after the formation of the zeolite filling and one effect has been to partly or completely alter the minerals originally filling the vesicles into a black amorphous mass resemblying coaly matter. He regards the oil indications as most likely due to natural distillation from oil shales by the vertical basic dyke, or as the result of relief of pressure by means of fissures on shales in a condition of advanced potential distillation owing to deep burial below the surface.

The remarkable resemblance between the South African and Western Australian occurrences will be at once recognised. The most important differences are:—

(a) The basalt at Oakes' Find is in places sheared or shattered, and is apparently more strongly impregnated with impsonite where it is sheared than where it is massive.

(b) Both the age and the succession of the rocks are different, the basalt at Oakes being overlain by limestone and underlain directly or indirectly by Devonian or Cambrian.

(c) No basaltic dykes have been found in the district.

(d) The vesicles of the basalt are in part empty, in part filled with calcite, etc., in part completely filled by impsonite. There does not appear to have been any impregnation of vesicular fillings by hydrocarbons, the whole of the impsonite being homogeneous and without a trace of silicate or other minerals.

(e) In no instance was any liquid oil found in any of the vesicles, though of course the number of specimens examined was very small.

VI.—ORIGIN OF THE IMPSONITE.

In the present state of knowledge of the geology of the occurrence it is impossible to come to very definite conclusions as to the origin of the mineral. Nevertheless, there are certain facts having some bearing on the question which are worthy of mention.

The occurrence of the mineral in vesicles and along cracks in the rock shows that it must have been formed after the basalt had solidified, and, in part at least, after it had been more or less decomposed and disturbed by minor or local stresses. These facts, together with a consideration of the composition, structure, and conditions of formation of the basalt, indicate that the original oil was not formed in the basalt, but has entered it from some other source.

Further, the fact that the material is most common along zones of shearing or cracking in the rock, and that there is apparently some degree of impregnation of the rock substance in the vicinity of the shear zone, strongly suggests that the shearing has allowed of the penetration of the rock by the original hydrocarbons in fluid form. It is possible, of course, that these hydrocarbons existed in cavities in the basalt before the shearing and that the latter allowed of a movement of the fluid in the rock mass itself.

Moreover, if, following the example of most authorities, we put aside the inorganic origin of oil, then the original material which, by inspissation formed impsonite, must have been derived from limestones, sandstones, or carbonaceous or oil shales, whether fossiliferous or not. As only limestones that have been dolomitised, fissured or jointed are known to contain petroleum in any quantity, only those affected in these ways need be considered. In addition, it has been pointed out by Craig* and others that the absence of phosphates in the composition of petroleum as well as their absence in the vicinity of any large deposit of oil is evidence against the derivation of any considerable quantities of oil from a limestone source. Even more weighty evidence is the history of the deposition of limestone deposits.† As the present generation of lime-secreting organisms lives on the fatty remains of the preceding generation, directly or indirectly, there is little chance of the accumulation of fats. No trace of fats, for example, can be found in a coral bank except on the surface. On the other hand, the consumption of the remains of plant life, the decomposition of which is delayed sufficiently to permit the burial of a great deal of it before complete decomposition, does not proceed in the same manner as is shown by the great quantities of finely-divided carbonaceous matter throughout so many shale beds and other formations.

The limestones in the district, so far as investigations have shown, are not dolomitised, channeled or fissured, and contain only doubtful traces of impsonite in proximity to the basalt. Sandstones are reservoirs for oil produced from other formations rather than deposits from which hydrocarbons may be derived by distillation.

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* E. H. Cunningham Craig: Oil Finding.

† See Principles of Oil and Gas Production: Johnson and Huntley, p. 20.

In view of these consideration, four hypotheses or explanations of the origin of the mineral in East Kimberley present themselves:—

1. That under the basalt there are formations containing carbonaceous or oil shales, that dykes later than the basalt penetrated them and distilled the hydrocarbons from the shales, and these hydrocarbons existed under pressure. Later, owing to shearing or faulting, there was a release of pressure along certain zones and the fluid oil condensed along the zones after impregnating the basalt to some extent. The inspissated oil itself may ultimately have sealed the fissures. The fact that the mineral can be traced on the surface for about five miles tends to invalidate this view for it is doubtful whether the amount of distillate produced by the intrusion of a dyke or of a few dykes would be sufficient to impregnate a zone of basalt which must be of considerable thickness and which apparently extends along a line of about five miles in length. Though, according to Hall,* the basalt on Madrid Farm is impregnated for a vertical distance of 42 feet and for a horizontal distance of 4,500 feet, the basalt in the vicinity of Oakes' Find is most probably of much greater thickness and has been impregnated for a far greater horizontal distance. Further, so far as is known, no dykes intrude the formations underlying the basalt. Of course, if the basalt flow is below the Cambrian limestone, then the possibility of the existence of carbonaceous or oil shales under it is quite negligible.

2. That carbonaceous or oil shales existed in some of the formations under the basalt, and owing to great increase of temperature as the result of deep burial of the rocks, they became in a state of potential distillation. When, owing to long subsequent shearing or faulting, channels were opened in the overlying basalt, the hydrocarbons rose through the sheared zone at first in gaseous and later in liquid state and filled some of the vesicles and cracks. The amount of distillate produced in this manner could conceivably be sufficient to impregnate a zone of considerable thickness and extent. If the limestone overlying the basalt is of Cambrian age throughout, then the chances of the existence of carbonaceous shales under the basalt, from which hydrocarbons could be distilled, are remote, and these compounds must then have been produced from shales overlying the basalt. If, however, some of the limestone is of Carboniferous age, then, as both shales and sandstones are known to exist in Hardman's Devonian Series, it is quite possible that carbonaceous or oil shales occurred amongst these, though they have not yet been discovered. The carbonaceous shales may have existed at a considerable distance from Oakes' Find, and as the basalt cover except where faulted or sheared would be impervious, the distilled hydrocarbons may have migrated to the zone where the pressure

* Loc. cit.

was released. On the other hand, the amount of shearing necessary to produce a shear zone extending from top to bottom of the basalt flow (or flows) must have been so great that some evidence of it more weighty than has been found so far must be forthcoming before this explanation can be received with any favour.

Both this and the previous hypothesis must be regarded as improbable.

3. That between the basalt and the overlying limestone, carbonaceous or oil shales are present in certain places, though, owing to overlapping or faulting, they do not appear in others; that by distillation of these shales, volatile hydrocarbons have been produced and these, under pressure, have followed along the plane of separation of the basalt or the shales and the overlying limestone and on emerging at the surface have impregnated the basalt to some extent at its junction with the limestone: that, in other words, the fluid oil has really migrated from places where the shales existed to others where escape at the surface was possible. The distillation of the hydrocarbons may have been brought about by heat and compression due to deep burial and folding of the strata. Though this hypothesis is more attractive in face of the known facts than either of the other two, it is still difficult to understand why, although the effective porosity of the overlying limestone is at least as great as that of the basalt, only the basalt should contain the impsonite in considerable quantity. One should expect at least an equal amount of the original oil or oil residuum in the limestone in proximity to the basalt. Yet up to the present only doubtful traces have been discovered, though this may be due to insufficient observation.

4. That the basalt is really composed of successive flows; that after one period of volcanic activity, there was such a long interval of quiescence that carbonaceous shales were formed in the surface of the basalt; that another extrusion of basalt then took place, and the molten lava flowing over the shales distilled the hydrocarbons from them. These hydrocarbons in part escaped into the atmosphere, in part became imprisoned in the vesicles or holes in the basalt. Subsequent local shearing and faulting (when the surface of the basalt had become weathered) caused cracks in the rock and the fluid hydrocarbons from the holes penetrated the cracks, and, later, both in the vesicles and cracks formed impsonite.

This explanation is feasible provided molten basalt is capable of occluding hydrocarbons without causing their disintegration or combustion, and as the distillation of the shales would have been completed long before the deposition of the limestone no appreciable amount of oil or oil residuum would be expected in the limestone.

SOME ADDITIONS TO THE KNOWLEDGE OF THE GEOLOGY OF KALGOORLIE, WITH SPECIAL REFERENCE TO THE OCCURRENCE OF A PORPHYRITIC OLIVINE PICRITE.

By R. A. Farquharson, M.A. (Oxon.), M.Sc., F.G.S.

Read 12th September, 1922.

The mines of the Golden Mile, *i.e.*, of an area of about one square mile, round and including the town of Boulder, comprise, as is well known, some of the richest in the world. The characteristic rocks of the mines are a greenstone which is an altered form of a quartz-dolerite, an albitic porphyry, and a graphitic schist or slate. The gold occurs in lodes or mineralised zones in the country rock and these lodes are chiefly the rather uncommon type known as composite lodes, which are really zones consisting of small fissure fillings of fairly parallel strike from which an extreme impregation and replacement of the country rock proceeded. Investigation has shown that no sharp boundary with the country exists, but that on either wall mineralisation gradually diminishes and the lode material passes into the unaltered green rock. In depth, these composite lodes extend at least as far as the bottom levels in the chief mines, and as the result of the recent discovery of fairly rich ore at a depth of about 3,000 feet in the Ivanhoe Mine, it is certain that the limits of ore deposition have not yet been reached.

In view of the phenomenal richness of the mines and of the width, depth and number of lodes, it was held by mining men early in the history of the field that it would be most remarkable if other mines comparable in importance and geologically similar were not to be found to the south of the Golden Mile group, and for years attempts were made by means of shafts and bores driven from the bottom of the shafts to pick up the continuation of the lodes. These attempts, however, met with no success, for south of a line drawn through Hannan's Star, the Black Crow, the Starlight and the Lake View Extended Leases, no composite lode was ever discovered.

Prospecting, however, for this continuation was and always has been attended with unusual difficulties. Even to a greater extent than in other parts of the Eastern Goldfields, and owing to the terrestrial and arid climate exrerienced by the interior of the State for countless years and to the peculiar type of weathering and decomposition the rocks have undergone in consequence of this

climate, there is a covering of brownish or reddish clayey material ranging from a few feet to at least 150 feet in thickness all over the country as far south as Hannan's Lake. There are few outcrops and even these are in a very decomposed condition, and there are on the surface practically no indications whatever of the nature and structure of the rocks below the covering.

As a result, therefore, of these peculiar geological conditions prospecting for the southward extension of the auriferous lodes was until recently largely confined to the sinking of shafts on the line of strike of the lodes and boring at inclined angles to the dip from the bottom or sides of these shafts. Much valuable information about the nature of the rocks was obtained by these methods and it was on this information that geological maps of the country to the south of Boulder were ultimately prepared, and considering the material available these maps have proved to be fairly indicative of the geological structure and constitution. As, however, from the very nature of the methods—as the shafts put down are not numerous, as many of them are of shallow depth, and as between most of them there exist considerable intervals of ground untested—the information at hand has always been more or less fragmentary and accurate delineation of the boundaries of the different formations has been impossible. In consequence, it has always been recognised that any new systematic scheme of prospecting would undoubtedly reveal additional facts which would cause some alterations in the existing maps.

The problem of picking up the continuation of the Boulder lodes is really one of finding the prolongation of the altered quartz-dolerite belt and of discovering sheared and mineralised zones in it As the method of investigation by shaft-sinking is very expensive and the results of the work are comparatively small, in order that fairly large areas of country could be tested, some other methods had to be adopted, and within the last two years more or less systematic prospecting has been carried out south of Boulder by means of the diamond drill.

The materials on which this Paper is based are chiefly the bore cores from the bores put down by means of these drills.

Within the last two years boring has been carried out in five different localities which have been marked on the accompanying plan:

1. On the Maylands Lease on the fringe of Hannan's Lake.
2. On Reserve 288H, Lease (5220).
3. On the Lady of the Lake Lease (5083), situated about one mile and three-quarters S.E. of the Great Boulder Mine.
4. On Lease 5072, Talisman; [5178] Bruce, and 5177.
5. On the British Flag Lease (5310).

1. *Maylands Lease.*—Boring on this lease was carried out by the Golden Ore Channel, Ltd., on sites fixed in part at least as the result of indications given by the divining rod. Three bores were drilled, the first, a vertical one, to 1,075 feet, the second, inclined at 75deg., to 1,316 feet, and the third, inclined at about 60deg., to 861 feet. Nothing to warrant the sinking of a shaft was found in any of the bores.

The rock of the three cores is essentially the same throughout, though in characters of minor importance it shows a considerable range. As a whole it is a dark-greenish or dark-grayish rock with white or pale-grayish spots that occur throughout the core from top to bottom, though they are much more common in some parts than in others. Commonly it is a porphyritic rock with white phenocrysts of felspar up to a quarter of an inch square and rare phenocrysts of quartz in a dark-gray ground-mass. In places, however, it is almost white, in others it is very dark green, in others again grayish-green, sheared, chloritic, and with small phenocrysts of felspar noticeable only with difficulty. Under the microscope the rock consists typically of well-shaped phenocrysts of turbid felspar, small phenocrysts of greenish hornblende and rare phenocrysts of quartz in a ground-mass composed of small squares, laths and grains of felspar, some granular calcite and minute scales of greenish chlorite. The species of felspar present are difficult to make out owing to the turbidity of the crystals which is due in part to kaolin, in part to granular calcite, in part to minute scales of muscovite. The commonest species, however, appears to be a plagioclase about oligoclase-andesine. The hornblende is in square or rectangular prisms, is of a rather pale-green colour, and in some crystals shows the orthopinacoidal twinning. Some forms are chloritised, others both chloritised and carbonated.

Some varieties of the rock are without hornblende, and containing as they do a considerable amount of quartz as phenocrysts, they very closely approximate in composition and structure to normal quartz-porphyries. Other varieties have neither quartz nor hornblende and closely resemble the albitic porphyries of other parts of the field. In a few places in the cores there are hornblende phenocrysts but no quartz.

A peculiarity of the rock is the occurrence in places of patches which from their irregular outline and paler colour appear to be xenoliths or enclosures of a foreign rock. Examination of these, however, proves them to be in all respects identical with some variety of the main body, and their occurrence is probably due (a) to the proximity of a junction of the rock with some other type, (b) to their being the first portions of the molten magma to be chilled and solidified, and (c) to the incorporation of these first

solidified portions in the molten or viscous rock and the ultimate solidification of the whole without movement, and so swiftly, that the molten magma had not time to re-act on the first-cooled portion.

The rock is typically a quartz-hornblende-porphyrite which is very similar to the hornblende-porphyrite already described from Bulong.

In the No. 2 Bore, at a depth of 909 feet, there occurs a marked change of country, the porphyrite giving way to a black graphitic schist or slate which is in places considerably brecciated. This rock is most probably the southward extension of the graphitic slate met with at a depth of 210 feet in the old Dingo Lease between Hannan's Lake and Boulder City. The relations between it and the porphyrite are of interest. For several feet before the main body of the graphitic slate is met with, small dead-black graphitic fragments make their appearance in the porphyrite, a fact which shows that the porphyrite has caught up these fragments when in a viscous state, and is consequently younger than the graphitic rock. The fact, too, that there are several abrupt changes from the graphitic slate to porphyrite and *vice versa* between 909 feet and about 1,200 feet suggests that the drill has gone down close to the junction of the two rocks and that this junction is somewhat irregular.

The graphitic slate shows no evidence whatever of having been derived from a quartz-dolerite by extreme shearing and impregnation by carbon. Both in composition and in structure it more closely resembles a true sedimentary slate than either a porphyrite or a greenstone.

In the No. 3 Bore, at a depth of 668 feet, the graphitic rock appears and shows at intervals to 679 feet.

2. *Reserve* 288E, *Lease* (5220).—Two bores were put down by the Golden Ore Channel Company on this Reserve, the first to 550 feet and the second to 313 feet 6 inches.

The rock from top to bottom of both bores is an albite porphyry or porphyrite in places showing quartz phenocrysts. It is in part sheared, in part sericitised and carbonated, and in part stained brown or brown-red by hydrated oxide of iron. In a few places some fine granular and cubic iron pyrites is present, and a few quartz veinlets cut through the rock mass. A rock identical with this has already been described by the writer in an article on the Petrology of the North End, Kalgoorlie, published in the London Geological Magazine, and no further description is therefore necessary.

3. *Lady of the Lake Lease.*—Mr. Arthur Williams, as the result of certain indications which he claimed to have obtained by the use of the divining rod, put down, largely at his own expense,

two bores on this lease. The core from the first of these, which went down only to 100 feet, was not officially examined. That from the second was a graphitic slate to a depth of 478 feet, but at this depth the slate gave place abruptly to an albite porphyry identical with that from the Golden Ore Channel Company's Reserve 288H, and with that already described in the article on the Petrology of the North End. The slate exhibited in places an incipient knotted structure, which is undoubtedly due to partial metamorphism and partial production of secondary minerals such as andalusite, caused by the intrusion of the porphyry. Both under the microscope and from chemical analysis the rock appears to be much more closely allied to a sedimentary slate than to a graphitised chlorite schist of igneous origin.

4. *Leases* (5072) *Talisman*; (5178) *Bruce*, [5177].—After his failure in the Lady of the Lake Lease, Mr. Williams, acting on the advice of the writer, again began boring in the leases just mentioned and some considerable distance nearer the line along which the Boulder lodes seem to die out. He has put down three bores, the first to 761 feet, the second to 447 feet, and the third, at his own expense, to about 100 feet. All three cores consist from top to bottom of amphibolised quartz-dolerite that has been more or less chloritised and which is essentially the same as the epidiorite that occurs in proximity to the Warden's House at Kalgoorlie. This epidiorite has already been described by the writer in Bulletin 69, G.S.W.A., pp. 25-26. The rock of the cores is also similar to the country rock of the Golden Mile, but, though it is in places slightly sheared, in places bleached and slightly mineralised by pyrites, in no part of the cores is it both sheared and mineralised, and therefore no lode material similar to that of the Boulder mines has yet been found in it. The bleached rock is almost white, yellowish or pinkish in colour, much carbonated, and shows leucoxene as small purplish-gray patches. The bleaching is caused by the action on the rock mass of solutions from below which break up the ferromagnesian mineral, produce a partial carbonation of the rock and form pyrites from the iron oxide left after the destruction of the ferromagnesian. This action has taken place both in the mines of the Golden Mile and in some of those of the North End, but in the former tellurides of gold were produced as well as pyrites.

5. *The British Flag Lease* (5310E).—One bore has been put down on this lease on a site chosen by Dr. Laver, of Kalgoorlie, his scheme being to bore eastwards at an angle of 45deg. and to a depth of 550 feet.

As the results of the examination of the core are very interesting from a geological point of view, a short general account of them must be given.

From the surface to a depth of 267 feet the rock passed through was the albite porphyry already mentioned. At this depth, however, the porphyry begins to show thin black strings and veins which become more and more common until at 267 feet 9 inches there is a sudden change from the porphyry to a rather fine-grained black rock. The latter persists to a depth of 308 feet and then gives place abruptly to the porphyry which contains the black strings and veins as before. From 308 feet to 314 feet the rock is porphyry, but at 314 feet the black rock again makes its appearance and persists to 316 feet. At 316 feet the black rock is displaced once more by the porphyry, and the latter forms the core to 346 feet 10 inches. At this depth the black rock once again comes in, but persists only to a depth of 350 feet. At 350 feet there is once again a clean cut junction with the porphyry, and this rock constitutes the core to the end of the bore.

Of the albite porphyry nothing further need be stated. The black rock, however, possesses such uncommon features that a somewhat detailed description of it is called for.

When fresh, the rock is black, of medium to fine grain, and unsheared. In places, particularly at and near its contact with the porphyry, it is aphanitic and almost glassy or flinty in texture. It decomposes at first to a dark-gray rock with white spots and finally to a grayish-white soft porous facies of comparatively small specific gravity. The specific gravity of the least decomposed specimens obtainable is 2.96. Under the microscope the constituent minerals of the rock are:—olivine, augite, felspar, magnetite, a carbonate, talc, chlorite, picotite.

Olivine is by far the most conspicuous mineral in the sections and forms about one-sixth to one-third of the normal rock. It occurs as large rectangular crystals wtih acute pyramidal terminations as large and small squarish crystals, and as rounded and irregular grains of different sizes. In some forms, traces of a cleavage //010 can be made out, and in all forms there are the usual irregular cracks and the shagreen surface. When the mineral has become somewhat decomposed it is replaced (in the larger crystals) by serpentine and magnesite or dolomite, or by the carbonate with hardly any serpentine; in the smaller crystals, by talc and the carbonate or by either talc or the carbonate alone. In those crystals in which the alteration is wholly to talc the crystal form has usually been preserved, but in those in which the alteration is to a carbonate the squarish or rectangular shape has been changed wholly or in part to a rounded one.

The mineral occurs in phenocrysts both large and small in a fine-textured reticulated ground-mass, and in nearly all the sections it forms the only phenocrysts. In very rare instances, the crystals

appear to have a thin border of augite. Careful examination of some sections shows that there is a small development of a second generation of olivine in rather minute squarish as well as round crystals. The squarish forms were at first thought to be cross-sections of augite prisms, but the absence of the characteristic pyroxene cleavage and the fact that the extinction in the forms is parallel to a side and not to the diagonal of the squares shows that the mineral cannot be augite. Moreover, in the aphanitic facies, similar small squares occur, some of which being now filled with talc have undoubtedly been olivine.

Augite occurs either in minute shapeless grains or in small prismatic or acicular forms in the ground-mass. The size of the grains and needles is so small that it is generally extremely difficult to identify the mineral, and it is only by the fact that the prismatic or acicular crystals give extinction angles up to 37deg. and exhibit twinning with the twin plane and composition plane 100, that the mineral can be identified. In the normal facies of the rock, the mineral occurs as minute rods, plumose aggregates of rods, linear aggregates of grains, or as individual small grains in the ground-mass, and the rods and aggregates form a minute network or plexus which closely resembles that of the felspars of some basalts. The prismatic forms are in places frayed or fibrous at one end and are somewhat similar to the microclites of some glassy basalts.

Felspar occurs noticeably in some facies and hardly at all in others. In all sections, it is present as minute microclites distributed in all directions in the ground-mass. The needles are so fine that they are only with difficulty discernible, but not uncommonly they are long and arranged in sheafy aggregates, the individual microclites being separated by granules and strings of granules of augite and of magnetite.

Magnetite occurs in fine granular form or as a fine dust scattered through the ground-mass, particularly in the facies in which the felspar occurs as long thin needles arranged in divergent groups and separated by linear aggregates of augite. In some sections it is present as a border round olivine grains that have been replaced by talc or the carbonate. Talc and dolomite or magnesite occur as decomposition products of olivine, chiefly replacing this mineral; and the chlorite scales have most probably been derived from the decomposition of augite.

Picotite is present in the rock in the form of small squarish or lozenge-shaped grains which are semi-transparent in the sections and of a deep brown colour. A few of the crystals were isolated by crushing the rock to powder and they proved to be octahedral in form. Moreover, partial chemical analysis of the rock gave .2 per cent. of chromium oxide, and this, together with the crystallo-

graphic and optical characters of the mineral, leaves little room for doubt as to the identity of the mineral. The picotite is almost wholly associated with the olivine in the rock.

Structure of the Rock.—The structure of the rock varies within a comparatively wide range. In the one facies there are large rounded, angular, and euhedral crystals of olivine in a very fine ground-mass composed of a network of minute prisms and grains of augite, granules of olivine, and a very minute plexus of felspar microlites, together with scattered granules of magnetite and the squarish crystals of picotite. At first sight the ground-mass appears to be made up of a plexus of *felspar* microlites and grains of augite, but more careful observation shows that the felspar forms only a small and almost indistinguishable part of the mass, and that the chief element of the ground is augite in very thin needles or rods, some of which show symmetrical extinction angles about 37deg.

In other facies there are phenocrysts of olivine of different sizes and small prisms of augite in a ground-mass of fan-shaped, sheaf-like and divergent groups of felspar microlites separated by minute needles of augite and granules of magnetite. This structure is somewhat similar to that found in variolitic basalts and in the glassy selvages of other basalts. In a few sections, particularly in those from the flinty facies, there are numerous euhedral crystals of olivine and prisms of augite in an extremely minute dark-grayish nearly black ground-mass which is of the variolitic type and almost irresolvable, but which on examination by high powers proves to be of similar composition to that of the coarser facies, with the felspars as mere threads.

Both in composition and in structure the rock bears a close resemblance to fine-grained olivine-basalts such as are found amongst the lowest lavas in the Bathgate Hills in Linlithgowshire in Scotland. The porphyritic character of the olivine, the presence of two generations of the mineral, the ground-mass composed of a plexus in part of augite, in part of felspar microlites, the sheaf-like or divergent grouping of the felspar needles and the large amount of fine granular magnetite scattered through the mass are features which link the rock with olivine-basalts.

On the other hand, the exceptionally large development of olivine, the fact that the differentiation of the ground-mass and phenocrysts is in places not at all well marked; that indeed in places there appears to be no ground-mass at all; the fact that the felspar in places almost wholly fails and the rock becomes a type composed largely of olivine and augite, these are characters which equally ally the rock with the ultra-basic plutonic picrites. Even in one and the same section of the rock can be seen parts resembling both in composition and structure olivine basalts and parts equally resembling ultra-basic picrites.

The most significant feature of the rock so far as its relationship is concerned is, however, the presence of picotite in all facies except perhaps the glassy selvages. Picotite is common in ultrabasic plutonic rocks and may be regarded as characteristic of some types of them, but so far as can be ascertained, it is not known to occur at all in olivine-basalts of extrusive origin. Even if it does occur in the latter in rare instances, the amount present cannot possibly be comparable to that in the rock under consideration. The presence of picotite, therefore, in addition to the characters mentioned above, clearly shows that the rock is really a picrite, that is, a type of ultra-basic plutonic and not an extrusive olivine-basalt. It is, in fact, a porphyritic olivine picrite with resemblances both to normal picrites and to somewhat glassy olivine-basalts, and is to be regarded as a hypabyssal representative of the plutonic picrites or peridotites. So far, such rocks have received but little notice from petrographers. Schemes of rock classification have made no provision for them. The differences between abyssal, *i.e.*, plutonic, and hypabyssal, *i.e.*, intrusive types amongst the acid, intermediate, and basic rocks are of course so conspicuous that distinctive names for the types have long been given; but as the differences between the abyssal and hypabyssal types among ultrabasic rocks are less conspicuous, no name has yet been given them, though these differences are noteworthy and significant.

Occurrences of a Similar Rock.—There are very few recorded occurrences of rocks of the peculiar character of this core in other parts of the world, but in his book on the Tertiary Igneous Rocks of Skye, Harker has described a sill which is almost identical both in composition and structure. According to him, the rock is dark, dense, of Sp. Gr. 3.14, showing abundant fresh olivines in a fine-textured ground. The mineral occurs in a second generation forming more or less rounded grains. Octahedra of picotite are present. The ground-mass consists mainly of innumerable slender rods of felspar with interstitial augite, the felspars having an arrangement as in many so-called variolites. The rock is mineralogically a picrite, its special features being the porphyritic development of olivine and the quasi-variolitic structure of the ground-mass.

In Western Australia itself a very similar rock has been recognised by the present writer from St. Ives District. It was first found 3 feet below the surface in a costeen 120 feet south of No. 3 shaft in Lease 4720, Ives' Reward, and a probable continuation can be traced in the next lease to the east, where the rock strikes roughly east and west and appears to cut a jasper bar at right angles. From the mode of occurrence of the rock in the Reward, cutting across the shear planes of the greenstone in which it occurs, it is most probably a dyke.

The rock is essentially the same both in composition and structure as the core from the British Flag Lease, though it differs in minor points. It is coarser in texture, and even in one section there are several abrupt changes from fine to coarse-textured facies. Apparently the rock before consolidation was very fluid, and portions subjected to sudden cooling formed fine-textured masses. The cooling of the whole rock, however, was so swift that the later-cooling portions had not time to react on the finer and earlier-cooled portions.

Field Relations of the Rock.—As already shown, between 267 feet and 350 feet in the core, the picrite is encountered three times, and each time, after persisting for some feet, it is displaced by porphyry. There can be little doubt, therefore, that the rock really occurs as tongues in this porphyry. Moreover, the black strings and veinlets, which though at first taken for picrite proved to be composed of calcite stained black by carbon, owe their origin, at least indirectly, to the picrite, for examination under the microscope of the junction between the two rocks shows a connection between the veinlets and the black rock, and as no carbon is present in the porphyry itself, it must have come in when the picrite was intruded. Again, the black rock at its contact with porphyry exhibits an aphanitic and more or less glassy selvage, whereas the porphyry never shows any selvage on the black rock. These facts, together with what is known of the mode of occurrence of the similar picrite in Ive's Reward, indicate that the picrite of the core is a dyke which is intrusive into the albitic porphyry and is consequently younger than it.

The Geological Results of the Examination of the Cores.

1. Those from Maylands Lease: The graphitic slate encountered in the bores on the Maylands Leases is both in mineral and chemical composition and structure much more probably of sedimentary than of igneous origin.

The relations between the graphitic slate and the porphyrite in the No. 2 Bore show that the porphyrite is intrusive into and consequently younger than the graphitic slate and also that a junction between the slate and porphyrite is very close to the site of these bores.

Moreover, the occurrence of the hornblende porphyrite in the bores shows that there is (between Hannan's Lake and the site of the bores) a belt of porphyrite which is continuous with that at Monument Hill and which in all probability is the same as that at Bulong. A considerable amount, therefore, of the area near the Lake mapped as amphibolite on Gibson's plan of Kalgoorlie and Boulder should be mapped as hornblende porphyrite so that neither

time nor money will in future be spent in prospecting it either by shafts or by bores. It is of course impossible with the knowledge at present on hand to fix the boundary of the porphyrite, but its northern limit appears to be near the site of the bores, and the belt most probably extends to Bulong.

2. Those from the Lady of the Lake Lease and from Reserve 288H prove that there is a much larger area of albitic porphyry south of Boulder than it has previously been possible to show on the geological maps, and very considerable areas marked on the 10-chain geological map of Kalgoorlie of 1902 as amphibolite, and on Gibson's 30-chain map of Kalgoorlie of 1910 as quartz diabase, should be marked as albitic porphyry. There is, in fact, good reason for stating that all porphyry dykes on the 10-chain 1902 map can be joined along the strike and the country between them is most probably also porphyry, and, as such, of little value for prospectors.

3. Leases 5177, 5178, 5072, of Mr. Williams: The cores from these leases prove that there is a belt of amphibolised quartz dolerite, *i.e.*, of rock very similar to the country rock of the Golden Mile, extending to the south of the Black Crow-Starlight-Lake View Extended line, beyond which no really valuable lodes have yet been found. How far the belt extends either north and south, or east and west, is not yet known, though bores now being put down may prove its limits. In that belt there does exist a possibility of the discovery of some lode of value, though the absence from the core up to the present of the facies showing pronounced shearing and shearing and mineralisation combined must be regarded as not altogether a favourable augury for the future.

4. *The British Flag Lease.*—The porphyry met with in this bore almost at the surface and extending down to at least 350 feet supports the statement made above that the area occupied by this rock is much larger than was thought. The chief interest of the rock, however, from the geological viewpoint is the occurrence of the picrite dyke. This rock is not only quite new so far as our knowledge of the petrology of Kalgoorlie is concerned, but if we except the rock from Ive's Reward, no similar rock has been recognised in the State, and only in very few localities in the world do rocks of the same nature occur.

Moreover, as it is younger than the albitic porphyry, it is undoubtedly the last rock to be intruded in the field. Whether it has arisen from the same magma and is of the same geological age as the olivine gabbro intrusions of the Warburton Range, or is the hypabyssal equivalent of the Bunbury basalt, are questions which cannot yet be answered, but as it is well known that particular rocks are intruded in different parts of the world at the same time the age of similar rocks in other parts of the world suggest that it is of comparatively recent origin.

CONTRIBUTIONS TO THE FLORA OF WESTERN AUSTRALIA.

No. 1.

By C. A. Gardner, Forests Department, Perth.

(Read before the Royal Society of Western Australia, 12th September, 1922).

Grevillea Yorkrakinensis, n. sp.

A low rigid shrub, branching from the base with numerous widely spreading branches; the branches slightly villous with appressed hairs.

Leaves crowded near the ends of the branches, linear-erete, 4 or 5-furrowed, glabrous, pungently-acute.

Flowers orange-yellow or red, in small axillary umbel-like racemes of 2 to 5 flowers, on short villous peduncles. Pedicels slender, villous with appressed hairs. Perianth pubescent without, the tube short, gibbous under the obliquely globular limb, villous inside near the throat. Torus straight. Gland not very conspicuous, semi-annular. Ovary villous on a short stipes situated on the upper margin of the torus. Style yellow, long and slender, glabrous, with a lateral orbicular stigmatic disk, which is convex or umbonate.

Fruit not seen.

In the Avon district, near *Yorkrakine,* in yellow sandy, gravelly soil, in low thickets, flowering in August.

Collector. C. A. Gardner, 4th September, 1922.

Shrub 6 to 10 inches high. Leaves .6 to 1.2 cm. long and .5 mm. wide. Peduncles 1-2 mm. long. Pedicels 2-3 mm. long. Perianth 6-8 mm. long. Style 1.5 cm. long.

The species belongs to the section *Plagiopoda*, and its closest affinity is *G. disjuncta,* F.v.M., from which it differs in its more prostrate habit, villous pedicels, sparingly pubescent interior of perianth and stipitate ovary, also in its straight torus and racemose inflorescence. From *G. haplantha* it differs in its glabrous style and shorter leaves, and from *G. Pinifolia* in its longer pedicels and shorter style.

The type is No. 1726 in the Herbarium of the Forests Department.

Grevillea cordata, n. sp.

A small erect but straggling shrub, glabrous with the exception of the branchlets and rhachis.

Leaves opposite, decussate, yellowish-green, sessile, broadly cordate-ovate, mucronate, with undulate margins, penniveined, the veins rather prominent.

Racemes dense, cylindrical, in terminal panicles, the rhachis softly and shortly villous. Flowers light yellow, quite glabrous. Perianth straight, divided to the base. Torus straight, without any gland. Ovary nearly sessile. Style slender, slightly exceeding the perianth, thickened at the summit, with an erect stigmatic cone which has a prominent rim at the base.

Fruit small, obcordate, the valves thin, smooth and yellowish-brown.

In the Avon district near *Yorkrakine,* in arid sandy soil on plains among other low shrubs, flowering in August.

Collector: C. A. Gardner, 4th September, 1922.

Shrub 3-4 feet high. Leaves 1-1.5 cm. long and 1-2 cm. wide. Racemes 3 to 5 cm. long. Pedicels 1.5-2 mm. long. Perianth 4 mm. long. Style 5 mm. long. Fruit 1 cm. long.

The new species belongs to the section *Anadenia* of Grevillea, but has no close affinities.

The type is No. 1727 of the Forests Department's Herbarium.

Kunzea sericea, Turcz. *var. glabra,* n. var.

This new variety is distinguished by its dark, almost black bark, and large, entirely glabrous leaves. The flowers are not known, and it is therefore possible that this may be a new species.

Summit of Mount Marshall, in crevices of granite rocks.

Collector: C. A. Gardner.

The type is No. 1714 of the Forests Department's Herbarium.

Ionidium epacroides, n. sp.

A rigid, erect densely branched small shrub with numerous branches, clothed with a minute pubescence in all its parts with the exception of the flowers, the short branchlets terminating in long sharp spines.

Leaves arranged in numerous dense lateral clusters, obovate or oblong, obtuse, keeled, slightly spreading.

Flowers in leafy spikes. Peduncles solitary, arising from the centres of the leaf clusters, stout, recurved about the middle, where there are two opposite obtuse bracteoles. Sepals obtuse, ovate, the two inner lateral ones slightly longer than the others, with spreading tips. Petals (with the exception of the lower one) ovate, obtuse, minutely denticulate-ciliate with spreading tips, of the same length as the sepals, the lower one twice as long, broad and truncate with a short broad claw, saccate at the base. Filaments shorter than the anthers, which are purple in colour, the connective produced into an orange-coloured oblong wing. Style short and straight.

The flowers are white in colour, the two lateral petals striate with two or three purple lines.

Seeds not seen.

Locality: Near Mount Marshall, half a mile south-east of Beneubbin station, in yellow sandy soil, among low shrubs and mallees.

Flowers months of May and June.

Shrub 10 to 16 inches in height. Leaves 2-2.5 mm. long. Pedicels 3 mm. long. Sepals 2 mm. long.

The type is No. 1696 of the Forests Department's Herbarium.

The new species appears to be quite distinct. Its rigid habit, pubescence, spinescent branches and straight style distinguish it readily from all other Australian species. It is only known from the single specimen collected. The few immature fruits seen were infested with grubs.

CONTRIBUTIONS TO THE FLORA OF WESTERN AUSTRALIA.

No. 2.

By C. A. Gardner, Forests Department, Perth.

Read 12th December, 1922.

Casuarina microstrobilus, n. sp.

An erect virgately branched shrub of 6 to 10 feet, the branches few and slender, prominently striate.

Internodes numerous, prominently striate or ribbed, whorls 9-merous, the teeth pale yellow, triangular, acute and *closely appressed.*

Male amenta not seen.

Cones pedunculate, depressed-globular, 1.3 cm. diameter and flat-topped. Bracts conspicuous, white, smooth, broadly cuneate with an incurved acuminate apex. Valves prominent, oblong, *obtuse* with a rounded apex; the dorsal protuberance not so long, attached near the middle broadly triquetrous-cuneate.

Achenes small, black with an oblique transparent wing, the style persisting as a median black line.

Shrub 2 to 3 metres high. Branchlets 7-9 cm. long. Cones 1.1 cm. long by 1.3 cm. diameter.

Foot of the western extremity of the Stirling Range in open forests of Wandoo (*Eucalptus redunca*, var. elata) in clay soil. 7th March, 1922. (C.A.G. 1774).

The species has a close affinity to *C. trichodon*, but the cones are not cylindrical, the bracteoles not acute and smaller, and the whorls of the branches are closely appressed.

Casuarina Helmsii, Ewart & Gordon.

This species is described in Proc. Roy. Soc., Victoria, 32 (N.S.), Pt. ii., 1920.

The description given is not very complete. I have to add the following:—

Dioecious. A shrub or small tree of 6 to 20 feet, with erect virgate branches.

Trunk to 6 in. diameter, but short. Branchlets glaucous, covered with a scaly, waxy covering which falls off as the specimen dries. Whorls in the specimens seen constantly 6-merous. Internodes numerous, usually about 17, smooth. The teeth of the whorls are acute, appressed, small, triangular and white.

Male amenta terminating short branchlets, 1.5 cm. long, the sheath-teeth broad, green and more or less spreading, not imbricate.

Cones: Bracts triangular, as long as or slightly shorter than the valves, villous without. Valves cuneate flat, villous on the back with broad triquetrous dorsal protuberances flat-topped and rugose, equal in length to the valves. Achenes red, with an oblique hyaline truncate wing.

Stony gravelly hills near Widgiemooltha, in open forests of *Eucalyptus stricklandi* and *E. torquata*. Fl. m. Sept. (C.A.G. 1770).

Casuarina spinosissima, Gardner, n. sp.

A rigid shrub of 6-10 feet with erect branches. Internodes numerous, not definite, but more than 25, long and glaucous, obscurely striate. Whorls 10-12-merous, the teeth short, erect, broad and scarious.

Male amenta not seen.

Cones rather large, broadly cylindrical, closely sessile, about 2 cm. long and 1.5 cm. broad. Bracts small, broadly oblong, villous without with a small acute narrow triangular apex, not half as long as the valves. Valves 4 mm. long, oblong, obtuse, villous in the lower half, the apex dark-coloured, the dorsal protuberance thick near the base and villous, produced into a long straight glabrous spine of 8 mm. in length.

Achene reddish-brown, the wing hyaline and oblique, with a small terminal black spot (the summit of the style).

Near Carrabin, in yellow sandy soil in thickets of *Hakea multilineata*. (C.A.G. 1273), October, 1922.

The new species belongs to the section *Acanthopitys* in Bentham's Flora, and has a close affinity to *C. horrida*, Herbert, differing in the more conspicuous bracts, more obtuse valves, larger cones and much longer straight spines.

Adenanthos intricata, n. sp.

A bushy shrub of 1 to 3 feet with erect rigid branches and a dark purple bark.

Leaves crowded at the ends of the small branchlets, trifid, densely silver pubescent with longer silky hairs intermixed, the segments terete obtuse, the apical gland only conspicuous in the older leaves.

Flowers small, solitary and terminal, scarlet. Bracts small, imbricate, broadly cuneate, ciliate on the margins. Perianth silky pubescent outside, densely bearded inside at the throat, the lobes narrow-oblong, not bearded behind or below the anthers, the connective-appendage prominent, red. Style long and tapering, with a narrow stigma.

Shrub of .4 to 1 metre high. Leaves 1-1.2 cm. long, the segments 8 mm. long. Perianth 1.4 cm. long, style 2-2.5 cm. long.

Bendering, in arid sandy soil on plains among low shrubs, notably *Grevillea hookeriana*. Fl. m. Oct.-Nov. (C.A.G.)

The species has a close affinity to *G. argyrea*, Diels, but has larger leaves, inconspicuous glands, and the perianth is densely bearded inside at the throat, but not so near the anthers.

The type is No. 1841 of the Forests Department Herbarium.

Grevillea arida, n. sp.

A small shrub of 3-5 feet with widely spreading branches, the bark smooth, almost black in colour.

Leaves linear-oblong, rigidly mucronate, with recurved margins almost to the midrib, glabrous and convex, nerveless above, silky-pubescent underneath.

Pedicels solitary or few clustered together, axillary or terminal, slender and almost filiform. Perianth glabrous outside, bearded within almost to the base with short recurved silky hairs, the tube narrow and attenuate, revolute under the obliquely globular limb. Torus very oblique, gland semiannular, truncate and prominent. Ovary glabrous, stipitate on the upper margin of the torus. Style long and slender, the stigmatic disc large, orbicular and lateral.

Fruit smooth, small and glabrous, acuminate, laterally attached.

Shrub 1-2 metres high. Leaves 1.4-1.8 cm. long and 2 mm. wide. Pedicels 6 mm. long. Perianth 1 cm. long. Style 1.8 cm. long. Fruit 1.2 cm. long, the stipes .5 cm. long.

The new species has a close affinity to *Grevillea acauria,* F.v.M., but the leaves are very different and the flowers larger.

Rocky hills near Widgiemooltha in thickets of *Casuarina Helmsii.* Fl. m. September.

The type is No. 1772 of the Forests Department Herbarium.

Acacia Pelloiae, n. sp.

A small rigid shrub of 3 feet with erect branches sparingly pubescent.

Leaves bipinnate; pinnae 2 to 3 pairs, the common rhachis angular with conspicuous glands just below each pair of pinnae, decurrent on the branches giving them a striate appearance, the secondary rhachises short and terminating in short spines rigid and black. Stipules very short, rigid, persistent and spinescent. Leaflets 2-4 pairs, obliquely-oblong, coriaceous, glandular seabrous, with short hairs, the margins recurved, the nerve near the upper margin.

Peduncles axillary and terminal forming a leafy cylindrical spike, solitary, much shorter than the leaves, bearing a cylindrical spike of yellowish-white flowers, the rhachis pubescent, the flowers 5-merous. Sepals united nearly to the summit, forming a broadly campanulate calyx more or less folded between the lobes and pubescent, the lobes broadly ovate. Petals valvate in the bud, united to about the middle into a 5-lobed corolla minutely silky at the base, the ovate lobes rigid, more or less concave and glabrous, obtuse.

Pod not known.

A shrub of about 1 metre in height. Leaves 2-2.5 cm. long, pinnae .5-1 cm. long; leaflets 4-7 mm. long and 2-3 mm. wide. Peduncle angular, 1 cm. long. Spike 1-1.5 cm. long and .5 cm. diameter. Calyx about 1 mm. long, petals 2 mm. long.

Near the summit of Bluff Knoll, Stirling Range, 3,400 feet altitude, flowering in October.

The species is known only from the fragment collected, consisting of a single twig with flowers. It is named out of compliment to Mrs. Pelloe who has collected many interesting specimens for me.

This new species has affinity to *Acacia Moirii,* E. Pritz, which I have not seen. The flowers are very similar, but the petals are not striate, the leaves and branches are not hirsute and the spikes are cylindrical, not ovate. It has affinity also with *A. strigosa* and *A. Drummondii.*

The type is No. 626a Herbarium (C.A.G.).

Pommaderris Mayeri, n. sp.

An erect shrub of 3 to 6 feet with spreading intricate branches; bark purple-brown, dark and smooth, the branches and leaves closely and shortly tomentose.

Leaves numerous on the short branchlets, obcordate or broadly obovate-emarginate, thick, hoary above, silky-pubescent underneath and more or less folded longitudinally.

Cymes small and dense, terminal, exceeding the leaves, the rhachis densely pubescent with reddish hairs. Buds globular or ovoid Flowers yellowish-white on thick pedicels tapering into the calyx. Bracts ovate, more or less concave, tomentose on the back, brown and scarious. Calyx turbinate, the tube short, silky-tomentose outside, the lobes large and ovate, marked inside with a conspicuous raised midrib. Petals spathulate with an attenuated base shorter than the calyx-lobes. Summit of the ovary convex, densely pilose. Style three-cleft, almost to the base, the branches much recurved. Fruit not seen.

Shrub 1-2 metres high. Leaves 5-7 mm. long and 5 mm. wide. Cymes 1 cm. long. Bracts 1 mm. long. Pedicels 1.5 mm. long. Calyx 3 mm. long, the lobes nearly 2 mm. long. Stamens 1 mm. Style 1 mm. long.

Stony hills near Widgiemooltha, among rocks in sandy loam with Cassia and Dodonaea. Fl. m. Sept.

The species is named out of compliment to Harold E. Mayer, who has given me every encouragement in my studies.

The new species has affinity to *Pomaderris myrtilloides*, and reposes in some herbaria under that name, notwithstanding the remarkable differences in petals and style.

The type is 1728 of the Forests Department Herbarium.

Darwinia collina, n. sp.

A bushy shrub of 18 ins. to above 2 feet in height. Leaves crowded and imbricate on the branches, ovate-elliptical, quite flat and yellowish-green in colour the margins narrowly scarious, minutely denticulate.

Involucres campanulate, the inner petal-like bracts yellow, entire, broadly elliptical-ovate, the outer ones shorter and green, the lowest passing into the stem leaves. Flowers numerous. Bracteoles about as long as the flowers, oblong-spathulate, obtuse. Calyx-tube 10-ribbed at the base, the ribs most conspicuous in the adnate part, the lobes very small, broadly ovate. Petals white, ovate-deltoid. Staminodia linear-filiform, very small. Style long and more or less flattened, bearded towards the end.

Shrub 40-60 cm. in height. Leaves 1 cm. long and 6 mm. wide. Involucre 2-2.5 cm. long. Calyx-tube 5 mm. long. Petals 3 mm. long. Style 1.3 cm. long.

Near the summit of Bluff Knoll, Stirling Range, Oct. 1922. Flowers m. October. Collector, Mrs. Pelloe.

(The type is No. 627a, Herb. C.A.G.)

The new species has affinity to *Darwinia fimbriata* and *D. macrostegia,* differing from the former in the flat leaves, entire bracts and ribbed calyx, and from the latter in the ovate bracts, smaller ovate flat and ciliate leaves.

Ericaceae.

Ericopsis, gen. nov.

Calyx-tube adnate; lobes 5. Corolla cylindrical, lobes 5, short, erect more or less valvate in the bud. Stamens 5, inserted at the base of the corolla; anthers erect, adnate, one-celled or very imperfectly 2-celled, opening to the base in longitudinal slits. Ovary inferior, 2-celled, with 4 or 5 ovules in each cell ascending from an axile placenta.

The genus consists of a single species. It is closely allied to *Wittsteinia* (a Victorian genus) particularly in the method of dehiscence of the anthers. The genus is typical of the *Ericaceae,* except that the anthers are one-celled, not two-celled as in the other genera of *Ericaceae.*

Ericopsis formosus, n. sp.

Stems prostrate, spreading to a diameter of 10 inches, with short ascending branches of not more than 1½ inches in height.

Leaves crowded and imbricate, erect, minutely scabrous-pubescent, linear-acute, concave, with minutely ciliate margins, pungently acute, and more or less glaucous.

Flowers large for the size of the plant, bright scarlet, erect and solitary, terminating the numerous short branchlets, sessile among the last leaves. Bracts none, or so much like the stem leaves as to be undifferentiated. Calyx-tube cylindrical, 5-furrowed, glabrous, the lobes narrow-linear and closely resembling the leaves, but with purple points. Corolla cylindrical, with short erect acute lobes induplicate valvate in the bud, the tube glabrous outside, and glabrous within except for a dense ring of spreading white woolly hairs near the base. Stamens free, inserted at the base of the corolla, with short slender terete filaments not one third the length of the corolla-tube. Anthers 1-celled, adnate, erect, light yellow.

Style about as long as the corolla, thick, terete, the stigma large and fleshy, capitate, with a convex surface divided by a raised line, glandular-papillose on one side, and glabrous, or minutely pubescent on the other.

Sandy rises on the east bank of the Hotham River, Popanyinning, among low shrubs in open "Wandoo" forest. Fl. m. December. (C.A.G. 1880).

This interesting species introduces a new family into the Western Australian flora. *Ericaceae* has Australian species only in Tasmania and the mountains of Victoria and New South Wales. It is of interest to find this endemic species occurring near the source of the Hotham and Avon Rivers.

A NEW MYRMECOPHILOUS BEETLE.

By J. Clark.

Read 14th November, 1922.

Family Ptinidae.

Enasiba mirocera *n. sp.*

Dingy castaneous-brown, elytra somewhat darker.

Head.—About as long as greatest width, truncated in front, sides evenly narrowed to base but eyes suddenly projecting; a deep semicircular, transverse impression between the eyes, and a feeble one in front; numerous pale, short, stiff setæ each arising from a puncture. Antennæ 10-jointed; first longer than broad, and curved; second half the length of the first, triangular, its apex closely applied to base of third; third not as long as the first, its apex produced; fourth and fifth bases truncated; sixth, seventh, and eighth subequal, slightly tapering to, and truncated at apex; ninth, similar, but rounded at apex; tenth, sides slightly rounded and dilated to apex, apex truncated.

Prothorax.—Longer than wide, widest at base, greately constricted at basal third, strongly and irregularly striolate, the sides well rounded to basal constriction, a well-defined median line with two tufts of yellow hairs at basal end, and a shorter impression at each side also terminating with a tuft of yellow hair; clothed with thick setæ.

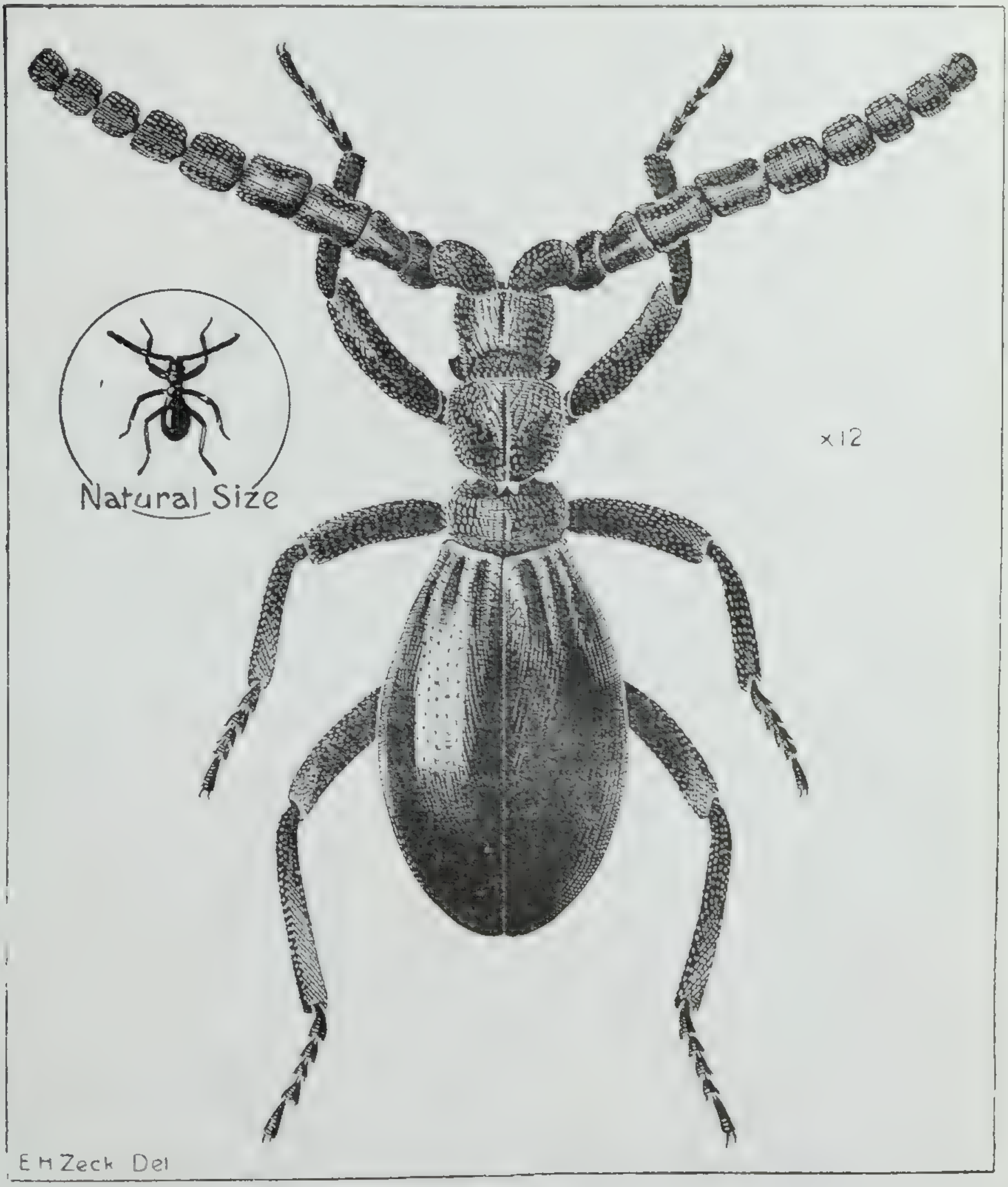
Elytra.—Strongly convex, elongate ovate, rather finely punctate striate, the interstices densely and finely longitudinally strigose, three large and deep basal impressions on each elytron, ridges between the basal impressions with setæ as on head and prothorax, setæ on disc very short but becoming longer on the apical slope.

Legs.—Densely covered with punctures and clothed with scales; femora and tibia grooved.

Underside.—Finely punctured, clothed with a few scattered scales.

Length.—3.5 to 4 mm.

Habitat.—Western Australia; Bunbury, Busselton. Found in nests of *Iridomyrmex conifer* Forel. (J. Clark).



E. Mirocera.

In general appearance close to *E. tristis Oll.* but may at once be distinguished by the antennæ. In the new species, these have been described from above, but, from the side, they appear very different. Viewed therefrom, the second joint appears equal in length to the first, and one-third longer than the third; at the base, the external edge is greatly produced towards the head; third joint slightly produced at apex, base closely applied to apex of the second; fourth slightly longer than the first, base rounded; fifth base same width as the third and fourth, but greatly reduced at

apex; sixth to ninth elliptical, greatly reduced at base and apex; tenth strongly and obliquely dilated to apex. From every direction the apical joint of *E. tristis* is seen to be smaller. Viewed from the side, the heads are very different. From the front, the head of the new species appears to have two shiny ridges close to each other, with another thinner ridge in front. From the side, the middle of the head appears to have an obtuse ridge. The impressions at the bases of the elytra of the new species are larger than in the case of *E. tristis*, and the interstitial striation is considerably less dense. The setæ on the head, prothorax and elytra are stronger and more conspicuous, but the fascicles on the prothorax are practically identical.

The genus was erected by Olliff in 1886 (Trans. Linn. Soc. N.S. Wales, 1886, p. 839) on a single specimen of *E. tristis*, and, in his description, he seems to have regarded the antennæ as eleven-jointed, for he says:—"The unique specimen upon which this genus is founded appears to have lost the terminal joint of each of its antennæ.'' The antennæ, however, prove to be ten-jointed. Olliff's description is good when the specimen is seen from one direction. The type of *E. tristis* remained unique until 1918, when, and since, many specimens have been obtained from nests of *Iridomyrmex conifer* in and around Perth. Specimens of *E. tristis* and *E. microcera* have been kept in an observation nest containing an active colony of the host ant (*I. conifer*) but, owing to interrupted observations, little information has been gained concerning the habits of either species. Both kept constantly on the move and were never seen to partake of food or water during the day. Both beetles seemed to be on friendly terms with the ants, and, during the three months' confinement, were never interfered with, but were allowed to move freely through the various chambers, including the nurseries which always contained a large number of larvæ and pupæ of the ants. On the beetles remaining quiet for a minute of two, one, and sometimes two ants were seen to attach themselves to the antennæ, and appeared to be getting great satisfaction by nibbling and licking the apical joints, stroking the beetle meanwhile with their antennæ. None of the ants were seen to attach themselves to the fascicles on the prothorax.

I am indebted to Mr. E. H. Zeck, of Sydney, for the accompanying plate, which he has drawn from a co-type.

EXHIBIT OF PORTION OF A LIVE COLONY OF HONEY ANTS.

By J. Clark.

(Shown on 12th September, 1922.)

(*Camponotus* (*Myrmophyma*) *inflatus*, Lubb.)

The colony shown contained workers, both major and minor, semirepletes and repletes of the Australian Honey Ant described by Lubbock from specimens obtained from Adelaide, South Australia, in 1880. These ants are numerous in the inland districts of Western Australia, being recorded from Kalgoorlie northwards to Marble Bar. The specimens exhibited were collected and presented to me by Mr. Jas. Hickmer at Jigalong, N.W. Australia.

The habit of developing repletes is known to occur sporadically in at least six different genera of ants, namely, *Camponotus*, *Myrmecocystus*, *Melophorus*, *Leptomyrmex*, *Plagiolepis*, and *Prenolepis*, the first, third, and fourth containing the Australian species.

The geographical distribution of the various honey ants seems to point to drought as one of the most important factors in their development, for nearly all of these insects are confined to dry plains and deserts of Australia, South Africa, and North America.

The impulse to develop repletes is probably due to the brief and temporary abundance of liquid food (Honey-dew, gall secretions, etc.) in arid regions, and the long periods during which not only these substances, but also all insect food is unobtainable. The honey collected is stored in the living reservoirs for the purpose of tiding over such periods of scarcity.

Froggatt (Report Horn Exped. 1896) says the repletes are quite incapable of movement, but such is not the case with the Western Australian species, as even the largest repletes can slowly move about, but are quite helpless if laid on their sides or backs.

The natives, and many white people, too, are particularly fond of the honey stored in the ant. It is slightly sour in flavour, but not unpleasant.

Mr. Hickmer informs me that the natives near Jigalong call this ant *Cul-cha*, and a little further south it is called *Oo-ka-da*. In his notes he says: ". . . They are edible to the natives; the nests are underground, and go down two and a-half feet through several small cells to a larger lot of cells where the 'honey-bags' are; the natives handle them carefully, as they are very easily crushed. They are only found in certain spots in scrubby mulga; the small entrance holes on the surface are generally covered with dry leaves."

CIDARIS COMPTONI, sp. nov.

A Cretaceous Echinid from Gingin.

By L. Glauert, F.G.S.

Communicated by permission of the Trustees of the Western Australian Museum, Perth.

Read 12th December, 1922.

Fossils from the Cretaceous Beds at Gingin have been known for many years.[1] In 1903 Mr. E. S. Simpson paid a short visit to the locality, when he obtained an interesting series of fossils which were examined by the late R. Etheridge, junior, Curator of the Australian Museum, Sydney. Mr. Etheridge determined certain Echinid spines (5556-242) as belonging to two species of *Phyllacanthus,* a genus known from the Cainozoic Beds of Willunga, South Australia.

In Bulletin 36 of the Geological Survey of Western Australia (1910) I compared these with the "numerous muricated Cidarid spines plentiful in the White Chalk and other Cretaceous Beds of Europe" and mentioned the presence of numerous hexagonal plates.

Three years later, Bulletin 55 was devoted to Mr. Etheridge's report on an extensive collection of fossils amounting to over 200 specimens. The Echinid spines were grouped under seven types, the general characters of all these spines being "quite in accord with those of the genus *Cidaris.* Some one or other was included in my premliminary list as *Phyllacanthus.*"[2]

A specimen which has recently come into my hands is sufficiently complete to enable me to attempt a description.

The specimen, which was collected by Mr. G. Spencer Compton, consists of an almost complete interambulacral area, to which are attached portions of the adjacent ambulacra. The large coronal plates above the ambitus are somewhat corroded, and those adjoin-

(1) For all references see Glauert, G.S.W.A. Bulletin 36, 1910, pages 118-9.
(2) Etheridge, G.S. W.A. Bulletin 55, 1913, page 12.

ing the apical disc and the peristome are imperfect; in addition, two of the upper plates have been pressed out of their normal position, so that it is impossible to give the exact dimensions of the test. It is estimated that the height of the test was 20 mm. and the diameter at the ambitus approximately 35 mm.

The ambulacral area is narrow, sinuous, almost straight; the plates simple. Tubercles in six rows at the ambitus, the outer the larger, mammillated, the next smaller and plain, the inner very small and not long persisting, the outer alone reaching the apical disc and the peristome. Each of the larger mammillated tubercles is opposite to a pair of pores. Poriferous zone narrow, depressed, each plate bounded by a slender ridge above and below, about fifteen plates in relation to the largest interambulacral coronal plate. Pores oblique circular, unigeminal, approximate, separated from one another by a septum supporting a rudimentary granule.

The interambulacral area is wide, about six times as wide as the ambulacral area at the ambitus; plates in series of five (?); boss small, plain, mamelon high, perforated; areola large, circular, depressed, surrounded by a ring of about sixteen mammillated, oval tubercles, a few smaller, mammillated tubercles placed beyond these fit in between the larger so as to complete the circle; miliary zone narrow, with closely approximated larger and smaller granules interspersed; sutures distinct. The median space is sunken, with a well-marked depression at the junction of the transverse and vertical sutures. Actinally the plates are broader than high, with scrobicular circles in contact above and below; apically the proportions are reversed and the circles are separated by a narrow miliary zone.

It is a matter of considerable difficulty to determine the exact systematic position of the Gingin specimen. I have not been able to find a diagnosis of the genus *Typocidaris,* but it would appear to be a cidarid with narrow ambulacra, round, approximate, non-conjugating pores, separated by a granuliferous septum; homogeneous granulation on the miliary zone of the interambulacral plates, and distinct sutural fossettes. *Cidaris*[3] has a small number of interambulacral coronal plates (5-8), with the ambulacra more or less undulating; the round pores of pairs rather close and separated by a nodule or ridge; and the primary tubercles perforated and crenulated. *Dorocidaris* has the ambulacral median area narrow; a small number of interambulacral coronal plates; scrobicles sunken and median space also. Tubercles without crenulation, and the oval pores of a pair without an intermediate groove.

Dorocidaris is a true Cidaris with no crenulation on the tubercles.

(3) See Duncan, P. M.: A Revision of the Genera and great groups of the Echinoidea, Journ. Linn. Soc. Zool. XXIII., 1889, pp. 31 and 31.

The Gingin specimen differs from *Typocidaris* in the rudimentary condition of the granule on the septum of the poriferous zone, the irregular size of the granules of the miliary zone, and the absence of distinct sutural fossettes. It may be described as a *Cidaris* with plain tubercles, or as a *Dorocidaris* with round pores. As Wright has shown in his "Monograph on the Cretaceous Echinodermata from the Cretaceous Formation of England" that the crenulation of the primary tubercle is not a constant feature in certain specimens or species, I consider it advisable to regard the echinid from Gingin as a *Cidaris* s.s.

Spines similar to those occurring in the Gingin Chalk are found on *Cidaris, Dorocidaris,* and *Typocidaris*; they therefore give no assistance in determination.

The literature available has enabled me to compare the Gingin fossil with a large number of Mesozoic cidarids from Europe, North America, North and South Africa, Sinai, Arabia, and India. The species that show the greatest resemblance are briefly referred to below.

Cidaris hirudo, Sorignet, 1850,[4] from the White Chalk of England and France, bears a strong superficial resemblance to the Gingin specimen, having round approximate pores and primary tubercles in series of 5 or 6, but the granular zone of the ambulacra is wider and the bosses of the primary tubercles are crenulated, not plain. Spines of a species closely related to, if not identical with, this have been recorded from the Cretaceous Beds of Pondoland, South Africa, and from the Utatur Cretaceous of Southern India.[5]

Cidaris pyrenaica, Cotteau, 1862,[6] from the Lower Albian of Gebel-el-Rekeib in Sinai, as shown by Fourtau's figure, is very near the Gingin form, but the boss of the primary tubercle is larger, the areola smaller, and the miliary zone more extensive with granules becoming smaller as they recede from the scrobicular circle.[7] Again, though the true *Cidaris* has the boss crenulated, and though the boss is so described by Fourtau, his figure shows a plain (smooth) boss.

Dorocidaris namadica (Duncan), 1887,[8] from the Cretaceous Beds (Aptian) of the lower Narbada valley of India, has more numerous primary tubercles, smaller mamelons, and the granules of the miliary zone decrease in size as they recede from the scrobicular circles; its ambulacral area is wider, the poriferous zone broader with oval pores, also twenty-five pairs of pores are opposite

(4) Sorignet " Oursins foss. de l'Eure, 1850: p. 17, and Wright, Mon. Brit. foss. Echin. from Cret. Form I., 1864–82, p. 64, Pl. IX., X., figs. 1–5.

(5) H. Woods. Ann. South Afr. Mus. 4, part 7, 1908, p. 276.

(6) Cotteau, Pal. Francs., Terr. Cret. VII., p. 201, pls. 1047 and 1048, figs. 1–10, 1862.

(7) R. Fourtau, Cat. Inv. Foss. de l'Egypte, Terr. Cret., Part III., 1921, p. 2, Pl.. I., figs. 1 and 2.

(8) Duncan, P. M., Rec. Geol. Surv. India, Vol. XX., 1887, p. 87, and plate figs. 1-3.

the largest interambulacral coronal plate. This species, also, has four rows of tubercles on the interporiferous zone at the ambitus, of which two only persist apically and actinally.

Dorocidaris dowsoni, R. Fourtau, 1919 (? 1921),[9] from the lower Albian of the Gebel Mandhour, Northern Sinai, is very closely related to the Gingin species, but the pores are oval, the granules on the septa more developed; there are but four rows of tubercles at the ambitus; the primary tubercles are in series of 5 or 6, the mamelon smaller, the areola less sunken, the median zone is narrow and but slightly depressed at the junction of the transverse and vertical sutures.

Dorocidaris jullieni (Gauthier), 1976[10] from Algeria, and occurring also in the Aptian of Gebel Mandhour and Gebel Oum Ragaoui in Sinai, of which I have not been able to see a figure or full description, has its primary tubercles in series of 6-7, with round scorbicular circles, rather deep, and all in contact above and below; the miliary zone is very narrow, and only visible on specimens of large size. The ambulacra have four rows of tubercles at the ambitus (six in large specimens), together with numerous minute, irregularly placed subsidiary granules, which latter are absent in the Gingin echinid. The pores are oval in a narrow, depressed poriferous zone.

Typocidaris malum (Albin Gras), 1848,[11] found in France and in the Albian and Aptian of Gebel Mandhour and Gebel G'tat el Zeit in Sinai, which has six rows of tubercles in a series at the ambitus and distinct sutural fossettes on the interambulacral areas, has the plates for the primary tubercles with more extensive miliary zones, which are covered with a homogeneous granulation.

Typocidaris proxima, R. Fourtau, 1920 (? 1921),[12] from the Aptian of Oum G'far, Rissan Aneiza massif in Sinai, has from 6 to 7 primary tubercles in a series, distinct sutural fossettes, and four rows of ambulacral tubercles at the ambitus. The figures show that this form has circular non-conjugating pores separated by a granuliferous septum, but the poriferous zone is wider, and there are but four rows of tubercles at the ambitus. The larger coronal plates have a much more extensive miliary zone with homogeneous granulation on all plates, including those which have the scrobicular circles in contact above and below; this feature is very distinct in Fig. 7a, but is not indicated in Fig. 7, where an imperfect test is figured.

(9) R. Fourtau, Cat. Inv. Foss. de l'Egypte, Terr. Crét., Part III., 1921, p. 4, Pl. I., figs. 3-4.

(10) Gauthier in Cotteau, Peron et Gauthier Echin. foss. de l'Algerie, fasc. III., 1876, p. 32, Pl. III., figs. 1–9.

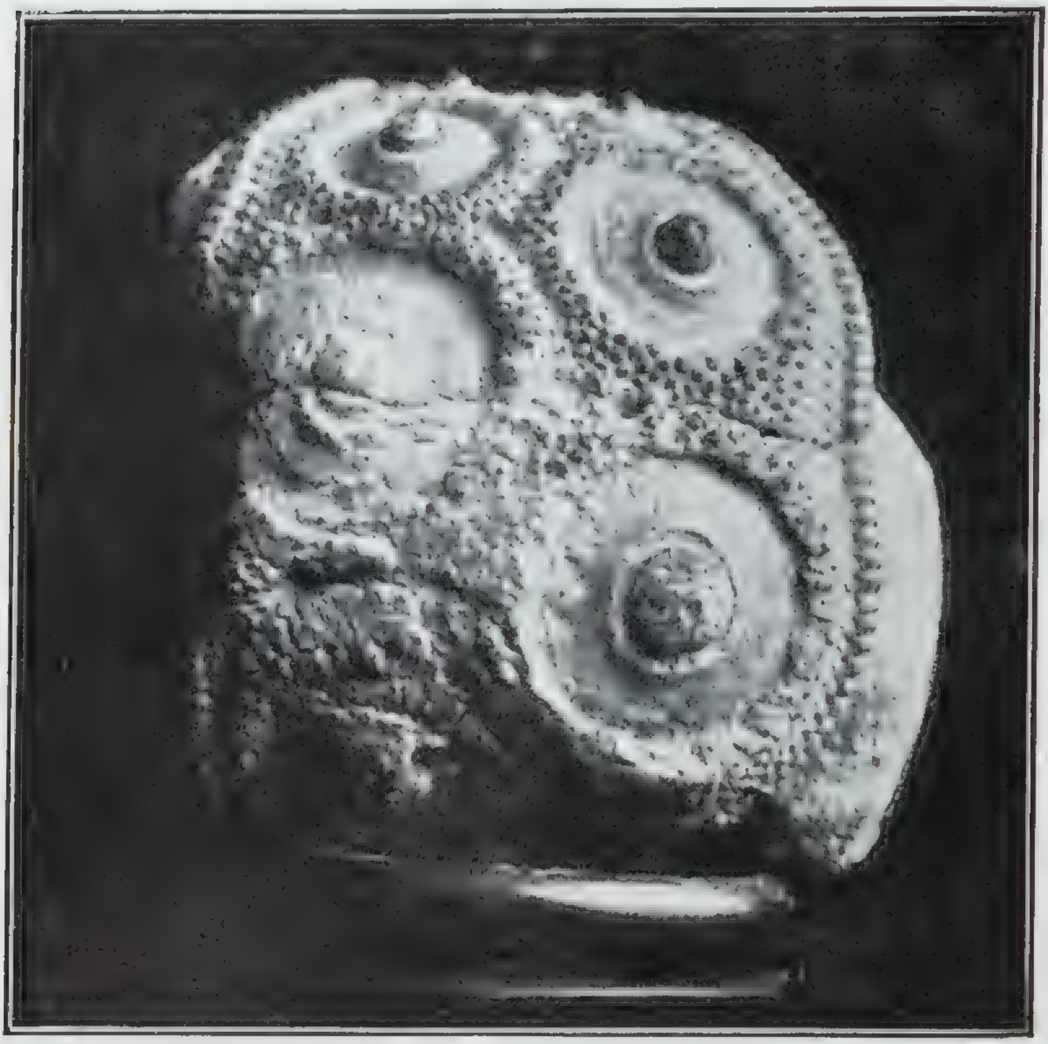
(11) Albin Gras, Oursins foss. de l'Isere, 1848, p. 22, Pl. I., figs. 1–3.

(12) R. Fourtau, Catal. Inv. Foss. de l'Egypte, Terr. Cret., Part III., 1921, p. 6, Pl. III., figs. 7–9.

The specimen from the Gingin Chalk, which is the first Echinid of Cretaceous age to be found in Australia, was collected by Mr. G. Spencer Compton, whose painstaking researches have increased our knowledge of the fauna of that limited and rapidly disappearing deposit. As a compliment to the discoverer I have named the species *Cidaris comptoni.*

The type, G 3775, is in the collection of the Western Australian Museum, Perth.

Plate III.



G. Pitt Morison, photo.

Cidaris comptoni sp. nov.

CONTRIBUTIONS TO THE FAUNA OF WESTERN AUSTRALIA.

No. 2.

A New Freshwater Tortoise from the Murchison River.

By L. Glauert, F.G.S.; Western Australian Museum, Perth.
Communicated by permission of the Trustees.

Read: 11th July, 1922.

During my visit to Milly Milly Station, Murchison River, a few months ago as the guest of Mr. D. Mulcahy, I collected two specimens of the Long-necked Tortoise inhabiting Milly Milly Creek.

The two carapaces indicated that the animals differed considerably from the known Western Australian *Chelodina oblonga*,[1] and suggested that I had discovered a new species. Efforts were therefore made to capture living examples, unfortunately without success, and I had to return to Perth without a perfect specimen.

Friends at the Homestead have subsequently forwarded two living tortoises, the larger of which, R1000, is described in this paper.

The Long-necked Tortoises (genus *Chelodina*), whose range is confined to the Australian region, have the neck longer than the dorsal vertebral column; no barbels on the chin; carapace with (normally) five vertebral plates, four pairs of costals, a marginal nuchal, and a pair of pygals; plastron with an intergular not reaching the margin, and six pairs of plates (The Animals of Australia, Lucas and Le Souëf). The extremely long neck and very short tail, as well as the position of the intergular plate, distinguish this genus from the other Australian fresh water tortoises—*Emydura* and *Elseya*.

The four specimens R911, R912, R1000, and R1106, show remarkably slight variation in the proportions and arrangements of the horny plates, differing in this respect from the south-western *Chelodina oblonga*, in which no two specimens are even approximately alike.

(1) Chelodina oblonga, Gray, in Grey's Trav. Aust. II., 1841, p. 446, Pl. VII.

The carapace is depressed, elliptical, slightly broaded behind, with indications of a broad shallow depression along the vertebral region; nuchal shield smaller than the marginals, much longer than broad, first vertebral shield longer and broader than the rest, fourth not shorter than the third, but narrower than the other members of the series, fifth both longer and wider than the second, third and fourth. Plastron about twice as long as wide, feebly angulated laterally, its greatest width in front of the bridge, considerably shorter and narrower than the carapace, the posterior notch which is angular in young forms tends to lose its sharpness in the adult; intergular longer than the pectorals or the femorals, fully twice as long as the suture between the pectorals; suture between the anals longer than that between the femorals.

Head, neck, and limbs as figured, neck and sides of head tubercular. Digits broadly webbed, a series of transverse lamellæ on the upper surface of the fore limb and on the lower surface of the hind limb.

Dark olive-brown above, plastron and lower surface of marginals yellowish; the younger specimens have narrow dark brown margins to the sutures on the under surface as in *Chelodina longicollis*,[2] but these markings are quite absent on the larger specimen, R1000. The general colour of the soft parts in the living animal is dark olive brown above and cream below. After death the colours fade.

The new species resembles *Chelodina expansa*[3] in the shape of its carapace and plastron, but differs from it in the proportions of the shields on the plastron. On the other hand it resembles *Chelodina novae-guineae*[4] in the shape of the plastron and proportions of its shields, but differs in the shape of the carapace. Apparently there are no transverse lamellæ on the under surface of the hind limb of *C. expansa* and *C. novae-guineae.*

Measurement of carapace, length 212 mm., breadth 184 mm.

Habitat.—Freshwater pools and creeks, Milly Milly, Murchison River, W.A.

The name proposed for the new form, *Chelodina milly-millyensis*, is suggested by the locality where the specimens were obtained.

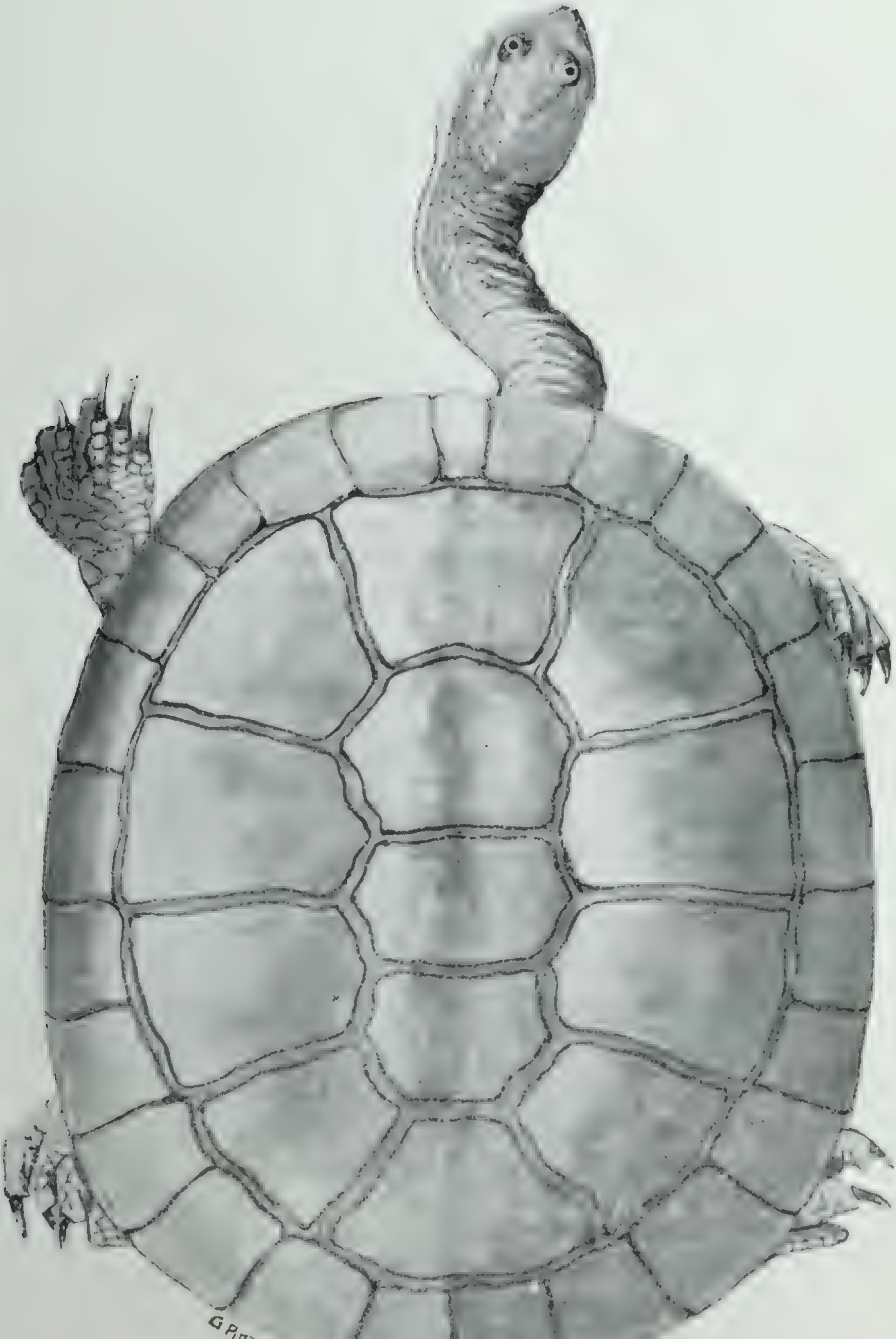
I am indebted to my colleague, Mr. G. Pitt Morison, for the excellent drawings illustrating this paper.

(2) Testudo longicollis, Shaw, Zool. III., 1802, p. 62, Pl. XVI.

(3) Chelodina expansa, Gray, P.Z.S., 1856 p. 370, Pl. XII.

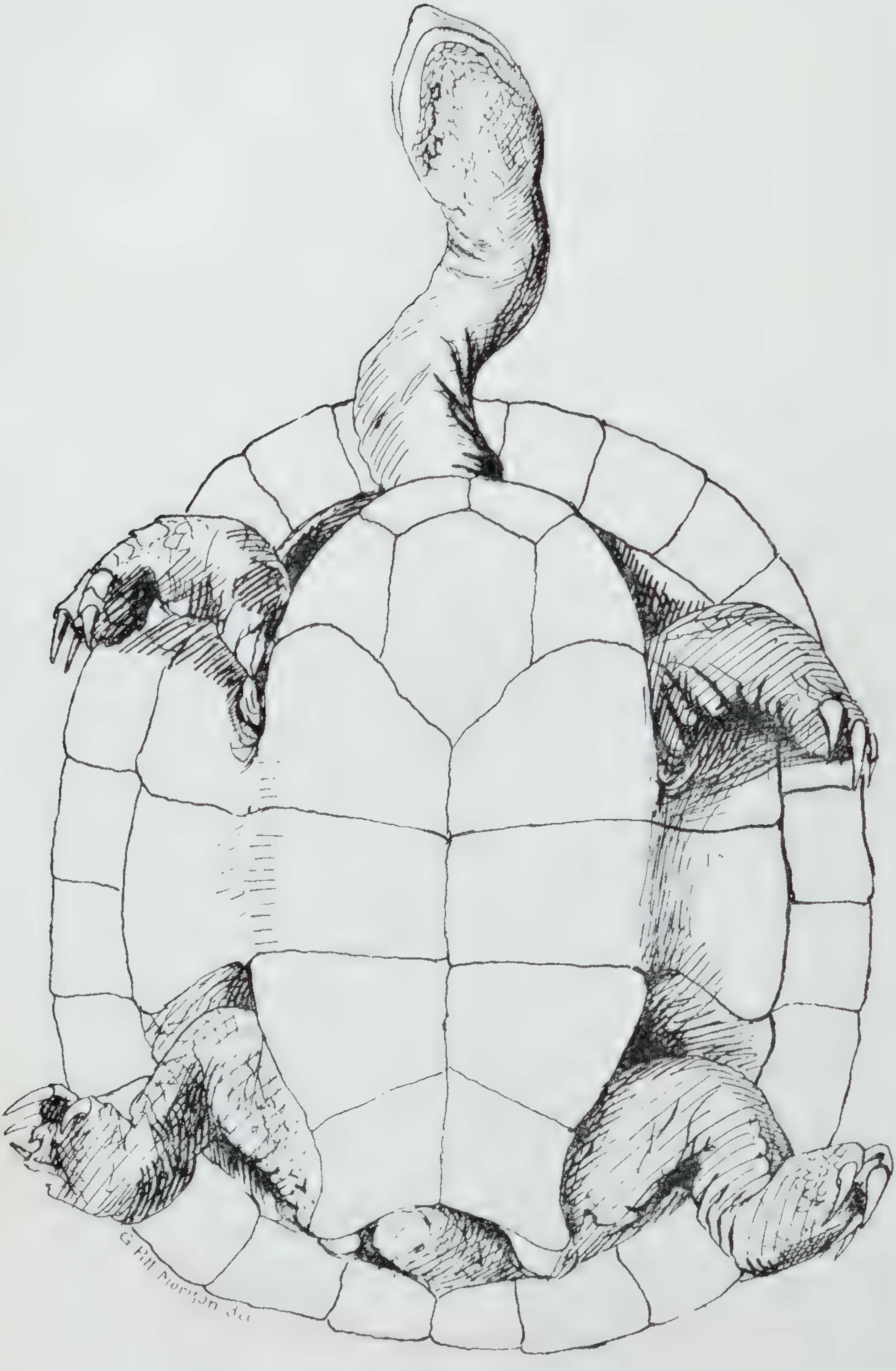
(4) Chelodina novae-guineae, Bouleng. Ann. Mus., Genova (2) VI., 1888, p. 450, and Cat. Chelon, B. M., 1889, p. 215, Pls. V., VI.

Plate IV.



Chelodina Milly-millyensis sp. nov.

Plate V.



Chelodina Milly-millyensis sp. nov.

CONTRIBUTIONS TO THE FAUNA OF WESTERN AUSTRALIA.

No. 3.

Annotated List of Lizards from Wallal.

By L. Glauert, F.G.S., Communicated by permission of the Western Australian Museum.

Read 12th December, 1922.

The Trustees are indebted to the Perth Observatory party, under Mr. C. Nossiter, for an extensive series of lizards collected during the recent visit to Wallal.

Of the eleven species represented four are new to the Museum collection, one form being apparently as yet undescribed.

Professor Ross, who accompanied the American party, also formed a collection of reptiles for the Biological Department of the University, two of the lizards he obtained—*Diplodictylus ciliaris* and *Physignathus gilberti*—not being among the Perth Observatory series, are included in this paper to make the list as complete as possible. These two specimens have been presented to the Museum by Professor Nicholls.

The locality Wallal, which is at the southern end of the Ninety-mile Beach, had never been visited by collectors. The British Museum possesses many specimens from Nickol Bay and Roebourne, 250 miles to the west, collected by a Mr. du Boulay, and this Museum contains a few specimens from the Pilbara collected by Dr. J. B. Cleland and Mr. H. M. Giles nearly 20 years ago.

The Reptilian fauna of the Broome district, 150 miles east, is fairly well known, as numerous collectors have visited that area from time to time.

FAMILY *GECKONIDAE.*

Rhynchoedura ornata, Gunther (two specimens).—This lizard, which is found in Western Australia, Northern Territory, South Australia, and Queensland, was first collected at Nickol Bay by du Boulay. The type is in the British Museum.

This species is new to the W.A. Museum collection.

Diplodactylus ciliaris, Boulenger (one specimen).—This fairly common lizard occurs in Western Australia, Northern Territory, Queensland, and Central Australia. The type is from Port Darwin.

Diplodactylus stenodactylus, Boulenger (one specimen).—This lizard has a limited range, the type locality being Roebuck Bay. I collected two specimens under stones at Milly Milly, Murchison River, in May, 1922. It is therefore not surprising that the species should be found at Wallal.

Peropus variegatus (Dum. and Bibr.) (two specimens).—A fairly common species under the bark of dead trees and in crannies, known from Western Australia, Northern Territory, South Australia, and Queensland.

FAMILY *PYGOPODIDAE*.

Lialis burtonii, Gray (three specimens).—This species, known at Wallal as the "Spinifex Snake," is found throughout Australia. The type was collected at Port Essington by John Gilbert.

FAMILY *AGAMIDAE*.

Amphibolurus maculatus (Gray) (ten specimens).—Occurs in Western Australia, South Australia, and Central Australia; it appears to prefer the more arid parts.

Amphibolurus reticulatus, Boulenger (58 specimens).—This is undoubtedly the commonest lizard on the plains of the Pilbara, Murchison, etc.; it is also found in other parts of the State, in Central and South Australia. The most southerly record for Western Australia is York (Michaelsen and Hartmeyer).

The lizard varies considerably in colour and pattern. Specimens under observation at Milly Milly were noticed to change colour, they were dull and blackish when kept in darkness, but assumed bright and vivid markings when exposed to sunlight. A reddish orange patch on the throat of the male was very conspicuous at all times.

The sexes are dissimilar; at Milly Milly the blacks regarded them as distinct species, the males being known as "munarra" and the females as "chubbi."

Physignathus gilberti, Gray (one specimen).—The range of this species extends through the North of Western Australia to the Northern Territory. The type from Port Essington was presented to the British Museum by Sir J. Richardson.

FAMILY *VARANIDAE.*

Varanus brevicauda, Boulenger (three specimens).—This species is confined to north Western Australia. As far as I can ascertain the specimens collected at Wallal are the first to be obtained since the types were collected at the Sherlock River and Nickol Bay by Dr. E. Clement.

FAMILY *SCINCIDAE.*

Tiliqua occipitalis, Peters (four specimens).—The collection contained four specimens of a lizard closely resembling *T. occipitalis*, but differing from Boulenger's description in the British Museum Catalogue of Lizards, Vol. III., p. 147, in the following points:—Frontonasal not in contact with the frontal; anterior temporals slightly larger than the others; ear opening larger than the eye opening, with five lobules; dorsal scales on the body largest, laterals smaller than the centrals; fore limb slightly shorter than the head, hind limb almost equal to the fore limb. The colour markings are also different, the head is whitish with a dark brown almost black mark extending along the side from the eye to above the ear opening, the body is pale brown with ten white cross bands between the fore and hind limbs, the tail is darker than the body with ten narrow white bands; the outer side of the fore limb is dark brown, outer side of the hind limb dark brown with five or six narrow white cross bands; under surfaces whitish with indistinct dark markings on the throat.

Measurements of specimen R1013:—

Total length	.. ..	310 mm.
Head	.. .. ..	49 ,,
Width of head	.. ..	38 ,,
Body	.. .. ..	170 ,,
Fore limb	.. ..	40 ,,
Hind limb	.. ..	43 ,,
Tail	.. .. ..	91 ,,

The name *T. O. nossiteri* is suggested for this variety.

Lygosoma (Hinulia) ocelliferum, Boulenger (three specimens).—This species is confined to Western Australia; the type is from Roebuck Bay. Drs. Michaelsen and Hartmeyer collected specimens at Beverley (two) and York (one). The three examples from Wallal are valuable additions to the Museum collection.

Lygosoma (*Hinulia*) *lesueuri,* Dum. and Bibr. (two specimens). —This, which is probably the commonest species of the genus, is found throughout Australia. Specimens are in the collection from Strelley River and Marble Bar.

Ablepharus muelleri, Fischer (one specimen).—The genus *Ablepharus* is represented in the collection by a specimen which agrees very closely with the description of *A. muelleri* although differing from that species in having four supraciliaries, instead of one only. A specimen, 9885, collected on the Strelley River by Dr. J. B. Cleland shows the same variation.

THE EMBIOPTERA OR WEB-SPINNERS OF WESTERN AUSTRALIA.

By R. J. TILLYARD, M.A., Sc.D. (Cantab.), D.Sc. (Sydney), C.M.Z.S., F.L.S., F.E.S., Entomologist and Chief of the Biological Department, Cawthron Institute, Nelson, N.Z.

(With three Text-figures.)

Communicated by Mr. L. GLAUERT on 12th December, 1922.

The Order Embioptera, or Web-spinners, is a small but very distinct and isolated group of insects, which represents, at the present day, a much reduced remnant of the great complex of insect types which are known as the Protorthoptera, and which existed in the Palæozoic Age. In the Upper Carboniferous these were chiefly insects of large or moderate size, with complex and reticulated venation. In the Lower Permian, owing to dry, torrid conditions, they show signs of reduction and simplification; the ancestors of the Web-spinners and other groups, such as the Earwigs or Dermaptera, can be detected there. After that, the fossil record of these insects is lost, owing to the extreme delicacy of the reduced wing-type; and we do not pick them up again until they appear, in the Baltic Amber of the Oligocene, as true Web-spinners, closely resembling those of the present day, and belonging to the same genera.

This small Order is divided into two families, viz., the Embiidae, in which R_{4+5} (or more rarely R_{2+3}) is forked either in both wings, or at any rate in the hindwing, and the Oligotomidae, in which both branches of Rs are simple in both wings. No representatives of the Embiidae have yet been found in Australia; a rather curious fact, as this family is undoubtedly more archaic than the Oligotomidae.

Only a single species of the family Oligotomidae has so far been recorded from W.A. This is *Oligotoma hardyi* Friedrichs, which occurs in and around Perth. By the kindness of Mr. L. Glauert, Acting Assistant in charge of the Biological Collections in the W.A. Museum, Perth, I have received for examination a number of specimens of a second very distinct species from Milly Milly Station, Murchison River, lat. 26°S., long. 117°E. Mr.

Glauert has also sent me specimens of *O. hardyi* Fried. in alcohol, for comparison with the new species. The study of these specimens enables me to point out some inaccuracies in Dr. Friedrichs' original description of *O. hardyi*—mistakes which were unavoidable owing to the drying up of the parts in the dead insect. These are corrected in this paper. The new species is here dedicated to Mr. Glauert, through whose kindness and interest in these out-of-the-way insects I have been enabled to study these specimens.

In describing Embioptera, it should be borne in mind that the males are always winged, and frequently come to light, while the females are always wingless, and are only found in their webs, or running about under rocks, etc., on the ground. The species of an extensive genus like *Oligotoma*, which is circum-tropical, can only be clearly separated on the terminal appendages of the male, though the wing-venation is also an aid, as in the present case. Thus it will be seen that it is inadvisable to attempt any diagnosis of species on characters of the female only; in this respect we are fortunate, as the specimens of both species sent to me consist entirely of males. For study of the appendages, the shrivelled end of the abdomen should be cut off and left to macerate in a solution of 10 % KOH for 24 hours or so. At the end of that time, it should be well washed in water, and either mounted in glycerine jelly, or else in Canada Balsam after dehydration in alcohol. The former mounts are the better, to my mind, as these rather soft appendages tend to harden and shrivel slightly after a time, if they have been passed through clove oil.

In order to understand the description of the appendages (Text fig. 2), it must be remembered that the Embioptera are remarkable in having the tenth tergite and the cerci of the male modified *asymmetrically* to serve as clasping organs during pairing. A process (*sp.*) attached to the ninth sternite, or developed in close relationship with it, is the true copulatory organ, or penis; above this, there are the two cerci (*lc*, *rc*), each of which consists of two segments, the right cercus remaining of normal form, while the left is modified in various ways, according to the species. Above the cerci lie the two halves of the tenth tergite, originally a single sclerite which has become secondarily and asymmetrically divided, and with a backwardly directed process developed from each half (*lp*, *rp*); of these processes, that from the right half (*rp*) is always the most prominent, standing out freely from the right cercus, while that of the left (*lp*) is frequently more or less engaged with a process or outgrowth of the basal plate on which the left cercus is carried. These parts are all named in Text-fig. 2.

The genus *Oligotoma* is the sole known genus in the family Oligotomidae. It can therefore be recognised at once, as far as the males are concerned, by the fact that the radial sector, Rs, has only

two branches, in both fore and hind wings. Text-fig. 1 shows the forewings of the two Western Australian species; they will be seen to differ only in size, in the arrangement of the cross-veins, and in the formation of the end of the radius, R_1. The veins themselves, with the exception of the strongly formed radius, are always either exceedingly fine or entirely obsolete; but their courses are clearly marked out by bands of brown pigment, between which there are paler or unpigmented areas carrying a number of special tactile hairs or macrotrichia (omitted in the figures).

Family OLIGOTOMIDAE.

Genus OLIGOTOMA Westwood, 1837.

Oligotoma hardyi Friedrichs.

(Text-figs. 1, 2, *a*.)

Friedrichs, K., Records of the W.A. Museum, 1914, vol. I., part 3, p. 241.

Dr. Friedrichs' description of the male is on the whole an excellent one, but it suffers from the fact that he had only the dried material to work upon. Dr. Friedrichs remarked that the species differed from both Enderlein's and Krauss's diagnosis of the genus *Oligotoma*, yet it was an undoubted member of that genus. He states that it differs from Enderlein's diagnosis in "the strong development of the median and the posterior branches of the radial ramus (*i.e.* Rs), and in the absence of a process on the left half of the tenth tergite." The stronger development of Rs and M is certainly a fact, and serves to separate the species from other members of the genus. It appears to me to be correlated with the somewhat larger size and stronger build of this insect. Usually in this genus the vein R_{4+5} is only partially developed, while M is generally only represented by its pigment band. But as regards the process of the left half of the tenth tergite, maceration of the appendages in KOH solution shows that this is certainly present (Text-fig. 2, *a, lp*); it is possible that Dr. Friedrichs mistook this process, if it was visible in the dried specimen, for part of the penis or process of the ninth sternite (*sp*), which he describes as apparently bifid. He also states that the species differs from Krauss's diagnosis of the genus "in possessing teeth on the much-thickened first joint of the left cercus." In the macerated specimen (Text-fig. 2, *a*) this part (*lc.*) is certainly thickened, but the inwardly produced portion is not toothed, as he says it is, but is only furnished with a series of stiff, short bristles. In the dried specimen, no doubt, the rather swollen bases of insertion of these bristles gave the appearance of a toothed margin.

Text-fig. 2, *a* also shows the true shapes of the two halves of the tenth tergite, which differ considerably from Dr. Friedrichs' description of them. The left half is the smaller of the two, and is sub-triangular in form; its process is attached to its inner angle by a very narrow base. The right half is also subtriangular, and much larger than the left; its process is merely a slight prolongation of its posterior angle, strongly chitinized apically, and with its apex slightly notched, as shown in Text-fig. 2, *a*, *rp*.

Text-fig. 1, *a* shows the forewing, in which it should be noted that R_1 does not bend strongly down to fuse with Rs, as in many species of this genus. The basal radio-median cross-vein (*r-m*) is placed quite transversely and is strongly developed. The number of cross-veins is exceptionally large, there being generally six between the costa and R_1, along the distal half of the wing, five or six between R_1 and the upper branch of Rs, two or three between the two branches of Rs, and two also between R_{4+5} and M. The last two series are rather weakly developed.

Measurements of forewing of the specimen figured are 11 mm. long by 2.6 mm. wide; of the hindwing, 9.2 mm. long by 2.1 mm. wide.

Female unknown.

Type: Holotype and paratype male in Coll. W.A. Museum.

Habitat: The types were captured at light in Perth. The specimens sent to me by Mr. Glauert were taken at Caversham, near Perth, but Master C. Kerruish, in 1915.

Oligotoma Glauerti, n. sp.

(Text-figs. 1, 2, *b*.)

Male: Total length 10 mm., forewing 9 mm., hindwing 8 mm.

General colour medium brown; legs and cerci brownish testaceous.

Head oval, with the *eyes* slightly projecting antero-laterally. *Antennae* pale brownish, 7.5 mm. long, with 21 segments, the first somewhat swollen, half as long again as the second, which is closely united with the third; third and fourth of equal length, each nearly twice as long as the second (Text-fig. 3, *b*). (In *O. hardyi*, the basal segment is much more swollen, and the third is nearly twice as long as the fourth; see Text-fig. 3, *a*). *Mandibles* at bases only as wide as, or a little wider than across the middle; right mandible with two apical teeth, the left with three; the right with a rounded projection on middle of inner margin, the left with a similar projection excavated in its middle. (Text-fig. 3, *b*). (In *O. hardyi*, the mandibles are much wider basally than across middle, the apical teeth larger, and the inner projections less prominent and closer to the teeth; see Text-fig. 3, *a*). Palpi pale brownish.

Thorax and legs of normal form, the fore tibiae only moderately swollen.

Wings subhyaline with pale brownish pigment bands; R_1 dark brown. R_{2+3} complete, but R_{4+5} only represented by a short basal piece and complete pigment band. M and anterior branch of Cu only represented by piment bands; straight stem of Cu present as a true vein. Basal radio-median cross-vein present, oblique. No true cross-veins between costa and R_1; from three to five cross-veins between R_1 and Rs; none between the two branches of Rs, and none between R_{4+5} and M.

Abdomen of normal form for the genus. Appendages as shown in Text-fig. 2, *b*; the right half of the tenth tergite narrower than the left basally, divided distally into two projections, the inner of which is finger-shaped, not strongly chitinised, the other (*rp*) very strongly chitinised, narrowly cylindrical, with its apex truncated and slightly excavated; left half of tenth tergite with a projecting piece (*lp*) carrying a strongly chitinised hook, which clasps the inwardly projecting end of the basal plate of the left cercus near its pointed end. Ninth sternite with a very slender, sharply pointed process (*sp*). Right cercus normal, the second segment (rc_2) slightly longer and narrower than the first (rc_1). Left cercus with the distal portion of the first segment strongly produced inwards into a transverse lobe (lc_1) reaching almost to the middle line; second segment (lc_2) almost normal, very similar to that of right cercus, but a little longer and slightly curved.

The form of the chitinised process of the right half of the tenth tergite, and the shape of the left cercus, at once distinguish this species very sharply from *O. hardyi*, Fried. The shape of the first segment of the left cercus also serves to distinguish it clearly from all other known species of *Oligotoma*.

Female unknown.

Types.—Holotype male and one paratype male in Coll. W.A. Museum; two other paratype males in Cawthron Institute Collection.

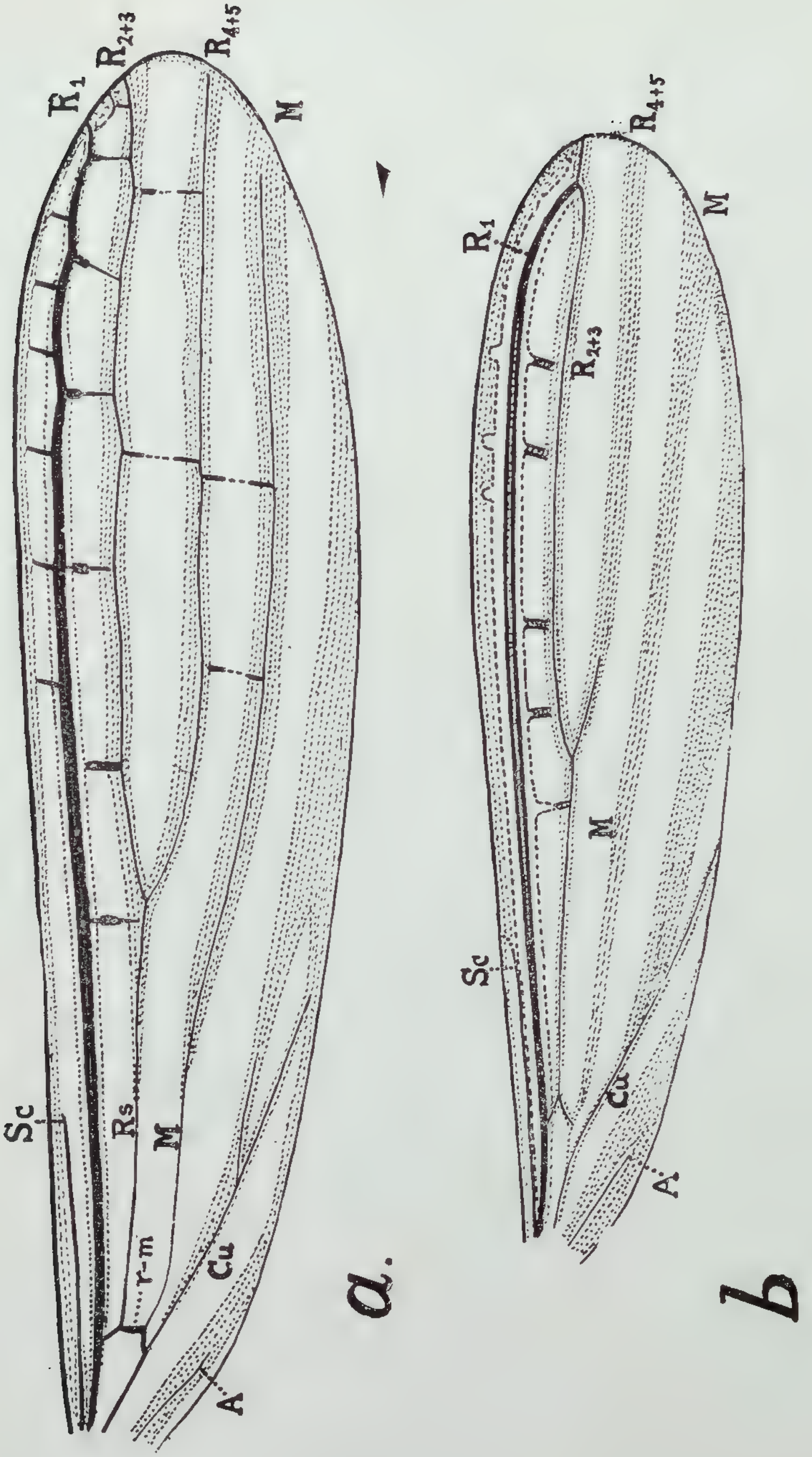
Habitat.—Milly Milly Station, Murchison River, lat. 26° S., long. 117° E.,; 25th May, 1922, taken by Mr. L. Glauert. The insects were attracted to light at night time.

The above four specimens have all been mounted on slides in glycerin jelly, and the description was made from the specimens in this condition, except for the colouring, which is paler in the mounted specimens. The drawings of the appendages in Text-fig. 2, *b*, is taken from one of the two paratype males in the Cawthron Coll.

Cawthron Institute, Nelson, N.Z.

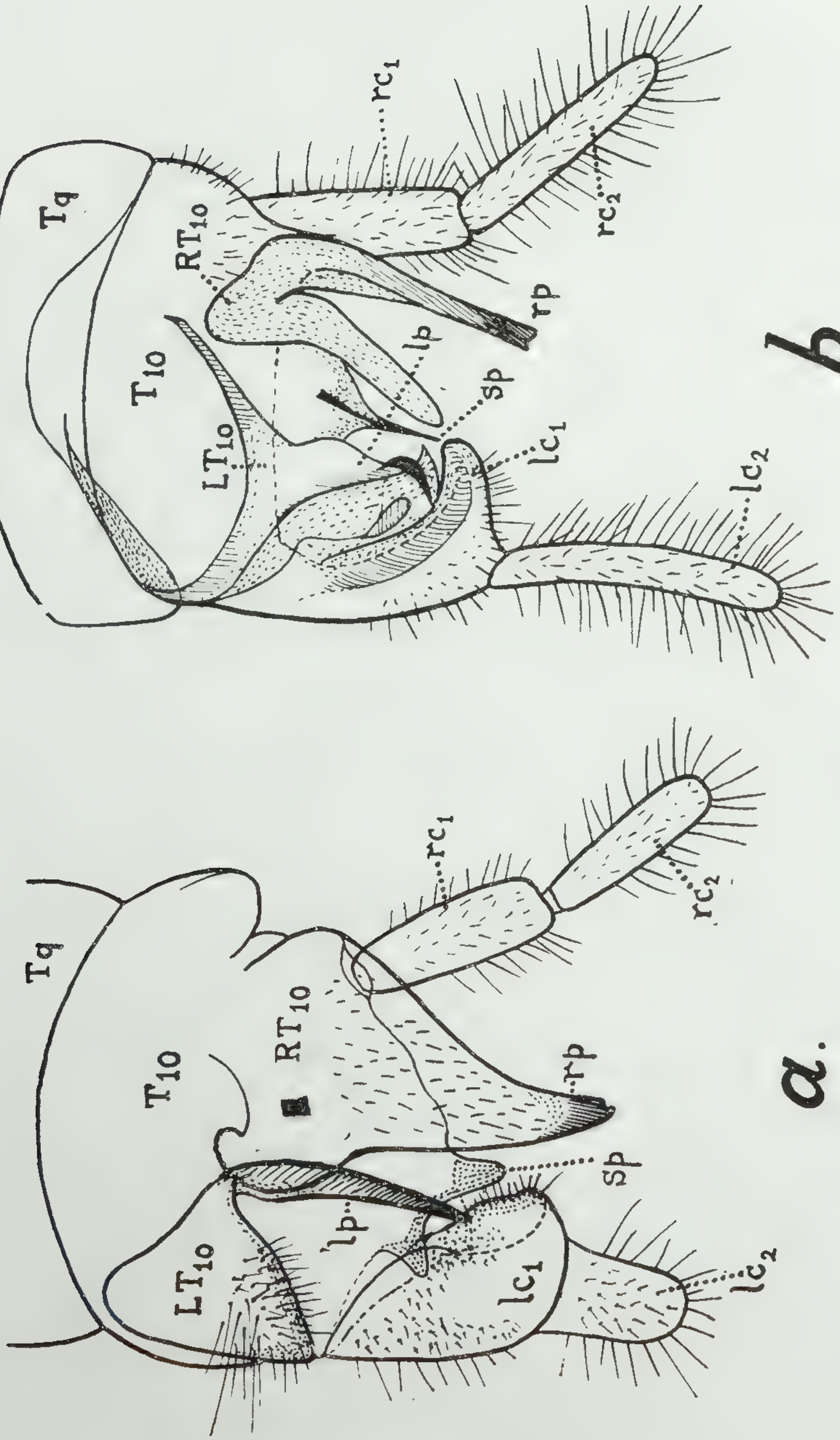
14th Nov., 1922.

Fig. 1.



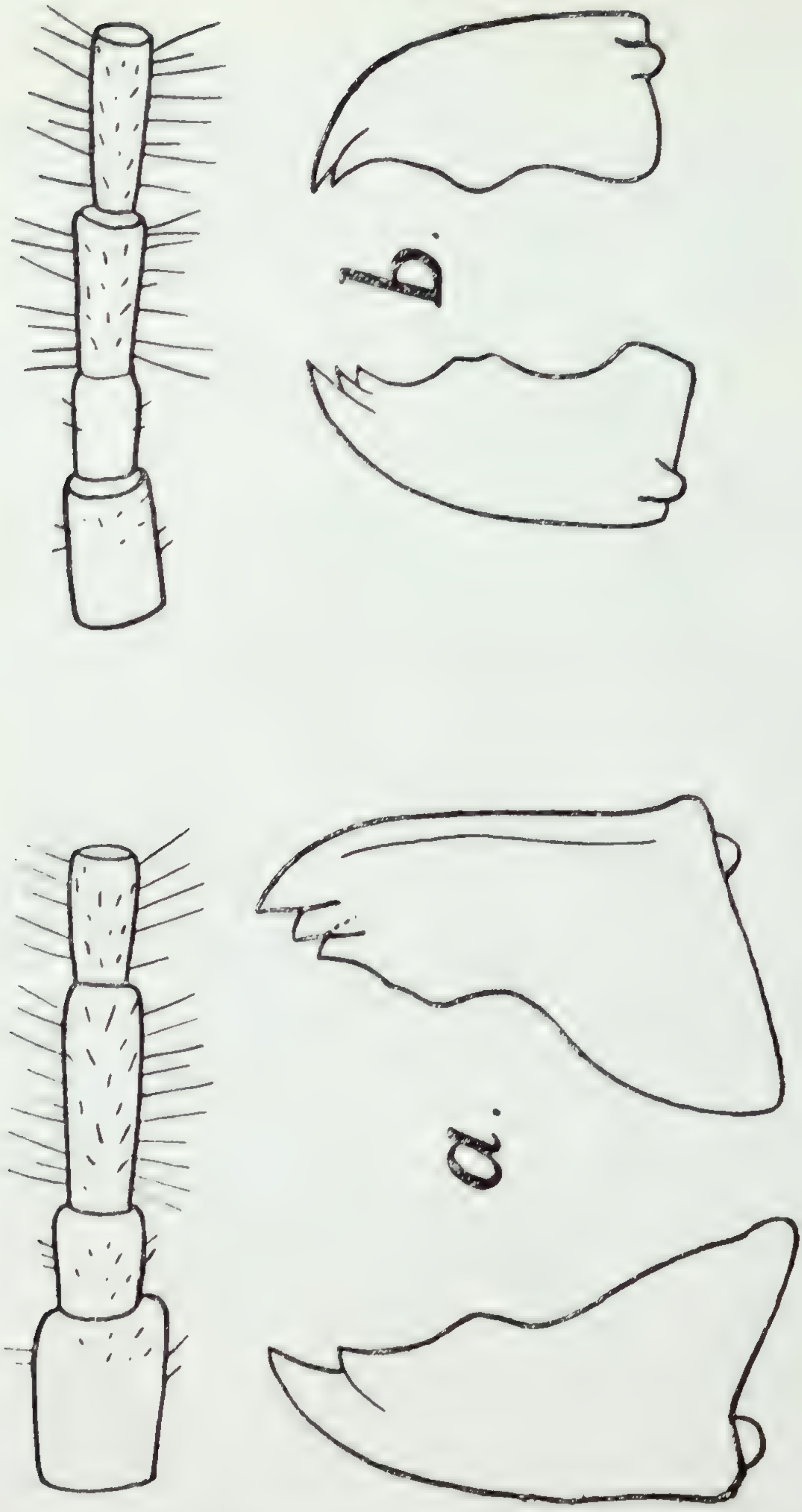
Text-fig. 1.—Forewing of *a*, *Oligotoma hardyi* Fried.; *b*, *Oligotoma glauerti* n. sp. A, anal vein; Cu, cubitus; M, media; R_1, main stem of radius; Rs, radial sector, with its two branches $R_2 + _3$, and $R_4 + _5$; *r-m*, radio-median cross-vein; Sc, subcasta. Macrotrichia omitted (× 9·6).

Fig. 2.



Text-fig. 2.—Terminal abdominal appendages of male in *a*, *Oligotoma hardyi* Fried.; *b*, *Oligotoma glauerti* n. sp. lc_1, lc_2, first and second segments of left cercus; *lp*, process of left half of tenth tergite, LT_{10}; rc_1, rc_2, *rp*, RT_{10}, same parts of right cercus and right half of tenth tergite; *sp*, process of ninth sternite (penis); T_9, ninth tergite (x 36).

Fig. 3.



Text-fig. 3.—The two mandibles and first four segment of antenna in *a*, *Oligotoma hardyi* Fried., b, *Oligotoma glauerti* n. sp. (x 45).

(In *a* the mandibles were drawn from beneath, so that their positions are interchanged ; the one with three teeth in the left mandible.)

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Journal and Proceedings

OF

The Royal Society of Western Australia.

PATRON : HIS MAJESTY THE KING.

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1923.

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THE JOURNAL

OF

THE ROYAL SOCIETY

OF

WESTERN AUSTRALIA.

VOL. IX., PART II.

PROCEEDINGS OF THE ROYAL SOCIETY OF WESTERN AUSTRALIA.

(*For half-year ending 30th June,* 1923.)

13th March, 1923.—The President, Mr. E. de C. Clarke, in the Chair. A letter was received from the Australian National Research Council inviting the Society to be represented at the Pan-Pacific Science Congress to be held in Melbourne and Sydney in August and September, 1923. A paper, illustrated by lantern slides, maps, and mineral and rock specimens, on "Secondary sulphates and chert of the Nullagine Series" was read by Dr. Simpson. Mr. L. Glauert read "Contributions to the fauna of W.A., No. 4," and also communicated a paper on "An Australian Cretaceous Cirripede" by Mr. T. H. Withers, of the British Museum (Nat. Hist.), London.

10th April, 1923.—The President in the Chair. Mr. L. Glauert exhibited (a) A Children's python (*Liasis childreni*) choked while endeavouring to swallow a spiny tailed skink (*Egernia stokesi*), (b) specimens of the spotted goby (*Gobius ornatus*) found in fresh water, (c) specimens of a fresh-water prawn (*Palaemonetes australiensis*), (d) specimens of a new fresh-water shrimp (*Chiltonia* sp.), (e) egg mass of a volute, possibly *Yetus diadema.* A joint paper on "The energy involved in the recent outburst of Beta Ceti," by Professor Ross and Mr. R. D. Thompson, was read by Professor Ross. Professor Shann delivered an address on the present position of foreign exchange.

8th May, 1923.—The President in the Chair. The President announced the withdrawal of the Council's recommendation to increase the annual subscription. The following papers were read:—(i) "Australian Formicidae," by Mr. J. Clark; (ii) "Contributions

to the Flora of W.A., No. 3," by Mr. C. A. Gardner; (iii) "Essential oils of certain W.A. plants," by Mr. L. W. Phillips, B.Sc.

19th May, 1923.—The annual conversazione was held at the University, the Governor, Sir Francis Newdegate, the Hon. Lady Newdegate, and about 230 guests being present. During the evening the following lecturettes were given:—"Calculating machine, wireless telegraphy and telephony," by Professor Ross; "Lights and lighting," by Mr. Orton; "The fruit fly," by Mr. Newman; "W.A. coal," by Mr. Compton; "Sickness in plants," by Mr. Carne; "A drop of water," by Professor Nicholls; "Some habits and customs of the Australian aborigines," by Mr. Neville. Exhibits were shown by Mr. L. W. Phillips, Mrs. T. Pelloe, Miss M. Creeth, Mr. A. Knapp, Mr. D. C. Burbury, the University Biology Department, and the W.A. Geological Survey Department.

12th June, 1923.—The President in the Chair. It was decided that the necessary alterations be made in the Rules in order to create the office of Assistant Librarian. An address entitled "Some defects in vision" was delivered by Mr. A. Knapp.

ANNUAL REPORT OF THE COUNCIL FOR THE YEAR ENDING 30th JUNE, 1923.

Ladies and Gentlemen,—

Your Council begs to submit the following report for the year ending 30th June, 1923:—

There are 154 members on the roll, of whom seven are Honorary Members, three Corresponding Members, 89 Ordinary Members, 40 Associate Members, and 15 Student Members.

During the year 13 Ordinary Members and 12 Associate Members have been elected.

The Council records with regret the death of Miss E. Johnson, an Associate Member of the Society.

Mrs. Lodge, Dr. Shearman, and Miss Palmer have resigned membership in the Society, their resignations to take effect from 30th June, 1923.

Thus there has been, during the year, a net increase of 12 in the Ordinary Membership of the Society, nine in the Associate Membership, and 14 in the Student Membership. Also, 20 further nominations for membership for the ensuing year have been received.

After a year's experience of the operation of the amendments to the Rules, whereby the secretarial work, hitherto performed by one Secretary, is divided between a Secretary for Physical Science and a Secretary for Natural Science, the Council can confidently affirm that the innovation is in every way successful.

Arrangements for excursions have been placed in the hands of an Excursions Committee to be appointed annually by the Council. The Council has authorised the issue of a membership card for circulation among members. This card is to contain a list of excursions for the forthcoming year, together with the dates of the General Meetings of the Society.

The Council has decided that in place of the volume of Journal and Proceedings (published hitherto yearly or half-yearly), papers will in future be printed immediately after being read, and issued separately in pamphlet form. Members will be supplied with a complete set of pamphlets at the end of the financial year, but during the year a member may obtain from the Publication Committee a copy of any particular pamphlet, in which case he will receive only the balance at the end of the year.

The Council desires to point out that in consequence of the above method of issue the whole cost of one year's publications has to be met in the next financial year. In addition, the expense of publishing Volume IX., Part II., which is now ready for issue, and

covers the period from 1st January to 30th June, 1923, will also be incurred at an early date. Thus the normal expenditure of a year and a half must be provided for during the next year. The Council, therefore, wishes to emphasise the necessity for securing an improved financial position, and trusts that this may be brought about, not by calling for further special donations, but by the revenue accruing from a steadily increasing membership.

There have been 13 meetings of the Council during the year, including two adjourned meetings, the attendance being as follows:—The President (Mr. Clarke) 13, Dr. Lotz 0 (absent from Perth during the greater part of the year), Professor Nicholls 9, Mr. Gibb Maitland 4, Professor Ross 8, Mr. Montgomery 3, Mr. Hancock 1, Mr. Sutton 5, Dr. Simpson 9, Mr. Allum 12, Mrs. Shelton 12, Miss Allum 12, Miss Reed 9, Dr. Dale 1, Mr. Glauert 11, Mr. Saw, 3, Mr. Shields 5, Secretary for Natural Science (Mr. Shelton) 13, Secretary for Physical Science (Mr. Thompson) 13.

There have been 10 General Meetings of the Society during the year, and one Special Meeting to welcome the members of the Wallal Solar Eclipse Expedition.

The following is a list of papers read before the Society:—

Clark, J.: A new species of Myrmecophilous beetle; Australian Formicidae; Honey Ants.

Farquharson, R. A.: Some additions to the knowledge of the Geology of Kalgoorlie.

Gardner, C. A.: Contributions to the Flora of W.A., Nos. 1, 2, and 3.

Glauert, L.: Contributions to the Fauna of W.A., Nos. 2, 3, and 4; *Cidaris Comptoni*, sp. nov.; An annotated list of lizards from Wallal.

Knapp, A.: Some Defects in Vision.

Pelloe, Mrs. T.: A visit to the Stirling Ranges.

Phillips, L. W.: Essential oils of certain W.A. plants.

Ross, Prof. A. D.: Scientific investigations at Wallal.

Ross, Prof. A. D. and Thompson, R. D.: On the energy involved in the recent outburst of Beta Ceti.

Shann, Prof. E.: The present position in International Exchange.

Simpson, Dr. E. S.: Secondary sulphates and chert of the Nullagine Series.

Smith, Dr. Donald: X-rays in Medicine.

Tillyard, Dr. R. J.: The Embioptera of W.A.

Trumpler, Dr. Robert: The structure of the Sidereal Universe.

Withers, T. H.: An Australian Cretaceous Cirripede.

The Annual Conversazione was held at the University (by permission of the Vice-Chancellor) on the evening of Saturday, 19th May. In addition to exhibits, several members gave short lecturettes which were repeated at intervals during the evening. The Council desires to express to these members its appreciation of their services, which so greatly contributed to the success of the evening.

(Sgd.) E. de C. Clarke,
President.

R. D. Thompson,
Joint Hon. Secretary.

ROYAL SOCIETY OF WESTERN AUSTRALIA.

Statement of Receipts and Expenditure for the Year ending 30th June, 1923.

RECEIPTS.

	£	s.	d.	£	s.	d.
Subscriptions :—						
1920–21	1	1	0			
1921–22	9	9	0			
1922–23	93	0	6			
1923–24	3	13	6			
				107	4	0
Special Donations				33	13	6
Reprints, etc.				5	9	6
Interest				1	14	5
Total Receipts for year				148	1	5
Balance in hand, July 1st, 1922—						
Cash	1	14	9			
Bank	1	18	3			
				3	13	0
				£151	14	5

EXPENDITURE.

	£	s.	d.	£	s.	d.
Government Printer :—						
Monthly Postcards ...	5	0	0			
Vol. 7 (balance) ...	6	7	9			
Vol. 8	25	10	0			
Reprints, Vol. 8 ...	2	15	7			
Vol. 9, Part I. ...	32	12	9			
Reprints, Vol. 9 (Part I.)	6	4	3			
Invitation Cards (1922 and 1923)	1	0	0			
Programmes (1923) ...	0	14	8			
				80	5	0
Museum Fees				14	14	0
Shelving				5	14	0
Wallal Social Expenses ...				4	8	8
Conversazione (1923), Expenses				3	14	3
Postage, etc.				13	10	6
Total Expenditure for year				122	6	5
Balance in hand, June 30th, 1923—						
Cash	3	2	6			
Bank	26	5	6			
				29	8	0
				£151	14	5

Examined and found correct.

F. B. CREETH }
A. R. GALBRAITH } Auditors.

ENID ALLUM,
Hon. Treasurer.

THE PRE-CAMBIAN SYSTEM IN WESTERN AUSTRALIA.

PRESIDENTIAL ADDRESS

By

E. de C. Clarke, M.A.

(Delivered on 10th July, 1923.)

CONTENTS.

I.—Introduction.

Pre-Cambrian rocks carry most of the mineral wealth of Western Australia, and therefore have been more studied than any group of rocks in the State. Geologists have described the characters of the various series contained in the Pre-Cambrians of a number of mining centres. But these places are separated by far larger tracts, the geology of which is only known in a broad way, and this isolation combined with the entire absence of fossils makes a wider correlation difficult. It seems to me, however, that some attempt at a general description of the group, more detailed than those given by Woodward (1895)* and Maitland (1919) is justified, especially as it will draw attention to many unsolved problems and diversities of opinion and will remind the geologists of our Society how much work both in field and laboratory lies close at hand.

* Dates in parentheses refer to papers listed in Section VIII.

II.—Distribution and Character of the System.

Of the 975,920 square miles occupied by Western Australia the latest geological map (Maitland, 1919) shows about 600,000 square miles* geologically mapped. Of this area about 380,000 square miles are occupied by Pre-Cambrian rocks.

Speaking broadly, we may say that, except in the Kimberley, Palæozoic and later rocks occupy a comparatively narrow coastal strip which passes into a broad belt running eastwards from the coast between Condon and Derby. Also a great band of comparatively youthful rocks runs northward from the Great Australian Bight, but whether this completely separates the Pre-Cambrians of the Goldfields from those of the borderland of Western and Central Australia is not known.

Comprised in the Western Australian Pre-Cambrian System is a very great variety of rocks, which lithologically may be grouped into—

1. Metamorphosed and unaltered acid igneous rocks.
2. Metamorphosed and unaltered basic and ultrabasic igneous rocks.
3. Metamorphosed and unaltered sediments.

North of Lat. 26°, the clearly sedimentary facies of the group predominates and a very prominent series of trend-lines runs east and west; south of Lat 26° the igneous facies is the more prominent and the trend is N.N.W. and S.S.E. as is shown, not only by the strike of the planes of schistosity, but also by the trend of the long axes of the patches, mainly of basic igneous rocks, which are scattered over a larger area of more acid rock, like chains of islands in a sea. In spite of these broad distinctions, however, sediments do occur in the southern area, igneous members of the system do cover considerable areas in the northern part of the State, and an east-west trend, crossing the much more obvious N.N.W. trend-lines occurs in many places south of Lat. 26°—as, for example, in the Stirling Range,† at Yuin (Jutson, 1914 *c*), and at Sandstone (Gibson, 1908), where the jasper bars run east and west.

It will be convenient, for descriptive purposes, to divide the Pre-Cambrian area of Western Australia into five provinces: the East, extending from the South Australian Border to about long. 127° E.; the West, extending eastwards from the coast to about long. 116° 30 E., northwards to about lat. 27° S., and also following round the south coast so as to include the Phillips River Goldfield; the Central lying between the East and West Provinces and extending north to about lat. 26° S.; the North-West covering the greater part

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* I am indebted to Miss E. Lamborne, B.Sc., for the more exact estimations to which these round numbers approximate.

†Positions of places, districts, etc., mentioned in the text will be found in Section IX.

of the Peak Hill, Gascoyne, Ashburton, Pilbara and West Pilbara Goldfields; and the Kimberley at the north end of the State. After some discussion of details, it will, I think, appear that each "Province" shows a certain amount of individuality in the character of its Pre-Cambrian rocks.

To establish any satisfactory general sequence in such a medley of rocks is obviously a difficult task, and, in order to arrive at any conclusions without entering on a very long discussion, it will be necessary to be apparently dogmatic and to omit mention of such earlier views as have been adopted or rejected by the majority of later workers.

III.—Age of the Whole System.

Maitland (1919, p. 8) writes regarding the supposed Pre-Cambrian age of this great group that there is only one instance on record in which age-determination rests on palæontological evidence. "In the Kimberley Division certain limestones, sandstones, quartzites, etc., have yielded lower Cambrian fossils . . . ; these fossiliferous beds are considered, and may be, newer than the schistose rocks of the vicinity . . . . . No actual junction has been noticed between the schists and the fossiliferous strata."

We are thus faced at the outset with lack of sufficient proof that the rocks under discussion *are* Pre-Cambrian. Assuming that the Kimberley metamorphic rocks are Pre-Cambrian—which is probable—there lies between them and the much larger areas of metamorphic rocks to the south a gap of two or three hundred miles covered (Maitland, 1919—map) by Carboniferous rocks, and, since the oldest fossiliferous rocks found in this southern area are Permo-Carboniferous, there is no absolute proof that the southern facies of the Western Australian metamorphic rocks is older than early palæozoic.

Nothing, however, is to be gained by labouring this point further, and for the rest of this address I shall speak without reservation of the whole series as Pre-Cambrian.

IV.—Relation between Granite and Greenstone.

In every part of the State, whatever other members of the Pre-Cambrian group may be absent, "greenstone" (*i.e.*, metamorphosed basic igneous rocks generally epidioritic in character), and granite are almost invariably present. The mutual relations of these two key rocks are therefore so important for the unravelling of the relative ages of the other types with which one or both will somewhere be seen in contact, that a discussion of their relative ages may well precede any attempt at establishing the general order of succession in the Pre-Cambrians.

Most parts of the West Province are composed of granite or gneiss cut by doleritic and gabbroid dykes which have been dynamically metmorphosed to epidiorite or even to hornblende schist, whereas the granitic rocks of the East Province are cut by great dykes of unaltered gabbro and dolerite and are themselves intrusive into epidiorites. Again, the granites of the Central Province are intrusive into epidiorites and are only to a minor degree cut by later dolerites and gabbros. In the North-West Province the granites are cut by epidiorite dykes and are themselves intrusive into older greenstones.

There is thus a marked contrast between the coterminous West and Central Provinces, and we are faced with the alternatives that the granite of the West is older than that of the Central Province, or that the epidiorite of the West is younger than that of the Central Province.

Now, at Bolgart occurs an epidiorite belt which (Feldtmann, 1920, p. 27) closely resembles the Central Province greenstones and probably forms the westernmost belt of these rocks. Feldtmann finds that the epidiorite is cut not only by acid rocks, but also by another system of epidiorite dykes, which also cut the acid rocks and are undoubtedly part of the series which cuts the Darling Range granite. Also, Montgomery (1908) believes that the greenstone dykes of Wagin and Darling Range are not quite the same in character and occurrence as the greenstones of the Central Province.

Again, near Ravensthorpe, where epidiorites of two ages occur, Maclaren (Montgomery & Maclaren, 1914) regards one series of these rocks as almost certainly older than the granite, while Woodward (1919) makes both younger than the granite.

Moreover in the Central Province in the south part of the Yalgoo Goldfield, Talbot (1920 *b*) noted a series of epidiorites which cut both ordinary greenstone and granite; and in the Yilgarn Goldfield (Blatchford and Honman, 1917, p. 68) the main body of the greenstone is intruded by hornblendite which is probably younger than the main granite, while the dolerites which at Forrestania (p. 131) appear to cut the granite are said to be similar to the Canning River dolerites (near Perth). Another similar instance is given in Blatchford and Honman, 1917, p. 161.

Particulars of the question of the relative ages of granite and greenstone in the North-West Province are scanty, but Maitland (1909, pp. 43 and 95) mentions an occurrence of "greenstone" dykes in granite at Mt. Samuel and Eramurra Creek. "Greenstone" implies rather epidiorite, like that which cuts the granite of the West Province, than unaltered gabbro or dolerite like that which cuts the granite of the East Province; but it is possible that "greenstone" is used by Maitland in a more general sense here, and that the greenstone dykes which he describes are the much younger gabbros and

dolerites of which there is a great development in this region—as, for example, near Corunna Downs homestead (Maitland, 1908, Frontispiece).

Available evidence therefore favours the view that the granite of the North-West, West and Central Provinces is substantially of the same age, but that in the West (and North-West?) Provinces occurs a later epidiorite than that forming the greenstone belts of the Central Province, although a few occurrences of the later epidiorites have been found near the western boundary of the Central Province. The question is, however, by no means as simple as may perhaps appear from the above statement, for it will be found on consulting the sections on the Yilgarn Series and on the later acid igneous rocks, that the granite is not all of one age.

V.—Relative Age, Character and Distribution of the Various Series of the Western Australian Pre-Cambrian System.

In this section will be outlined briefly the lithological character, etc., of the various series of which the Pre-Cambrian Group of Western Australia is composed. These series will be arranged in what seems to be the most probable order of succession, the oldest being placed first.

A.—Yilgarn Series.

In the Central Province the greatest development of these rocks is found in the Yilgarn Goldfield—hence the name which I suggest may be applied for convenience of reference, to the series throughout the State. At Westonia, Bullfinch, Parker Range, Marvel Loch and Ennuin (Woodward, 1912*a*, Blatchford, 1915, Blatchford and Honman, 1917) are found "chiastolite and andalusite shales, quartzites, graphitic quartzites and crushed quartz conglomerates" which Blatchford and Honman consider to be the oldest series of rocks in the Yilgarn Goldfield. Woodward (1912*a*) also suggests that the hornblende-biotite and albite-muscovite granite of the north part of the Yilgarn Goldfield may be of sedimentary origin. Mention of this and other areas of granite-like rocks which are thought by some to be highly metamorphosed sediments will be found in subsection D.

Probably the conglomerate series at Kanowna (Blatchford and Jutson, 1912) is to be classed with the Yilgarn Series. These conglomerates have been dynamically metamorphosed and also interstitially intruded by a rock now metamorphosed to amphibolite.

Under this series also may possibly be included the schists of Gibraltar centre near Coolgardie, since Blatchford (1913), supported by petrological work, regards them as sedimentary, and since there does not seem to be any clear evidence of their age

relative to the Kalgoorlie ("greenstone") Series. Feldtmann, however (1922), considers that they are either sheared greenstones (Kalgoorlie Series) or a sheared grano-diorite different in age from the Kalgoorlie Series.

Between Warriedar and Yalgoo (Specimens obtained by Mr. Maitland and myself, descriptions not published) and near Mt. Kenneth (Talbot, 1920*b*, p. 9) are occurrences of highly metamorphosed rocks which in the field and under the microscope give evidence of their sedimentary origin. Other metamorphosed rocks at Yandhanoo Hill and at Warriedar mentioned later under the Mosquito Creek Series may also belong to the older Yilgarn Series.

Gibson (1909, p. 18) in the country near the transcontinental railway route found that in the large area occupied by granite of the ordinary type, is a belt of garnetiferous gneiss running from Simon Hill for about 100 miles in a N.N.E. direction. This he regarded as older than the granite, and it may therefore belong to the Yilgarn Series.

Several other reported occurrences of "older granite," mentioned under the heading of Later Acid Rocks, might be included here. Possibly in some or all of these we have remnants of the acidic earth-shell the formation of which marked the beginning of geological time.

At Leonora occurs a finely foliated much granulated quartz andalusite schist of sedimentary origin (Maitland, 1909, Clarke, X1), and in other places in the Leonora-Duketon district metamorphic rocks of clastic origin, including a black carbonaceous chiastolite slate, have been found (Clark X1).

At Quinn's (Feldtmann, 1921*b*) is a series of quartz-andalusite and quartz-chlorite gneisses and chlorite-talc schists with probable andalusite, which resemble lithologically the rocks just described. Feldtmann, however, regards the Quinn's rocks as representatives of the Mosquito Creek Series, whereas the other occurrences described in this section are thought to form the basal members of the Pre-Cambrian Group.

In the West Province several isolated occurrences of exceedingly metamorphosed sediments, apparently the bottom series of the Pre-Cambrians, are recorded:—

In the Phillips River District (Woodward, 1909) at least three occurrences of andalusite schist have been noted, and it seems likely that the acid schists, classed by Maclaren (Montgomery & Maclaren, 1914) as the oldest rocks of the district are also part of this series. Near Kendenup and along the Kalgan River also the country is composed of highly metamorphosed and sheared ancient sediments tilted at a high angle (Woodward & Blatchford, 1917).

Regarding the western part of this Province the late Mr. H. P. Woodward was of opinion (letter to myself) that the "Darling Range granites" are mainly metamorphosed sediments. Mr. Woodward was approaching the completion of an extended report on the South-West Division when he died, and not the least of the misfortunes accruing to geological science from that untimely event is that we have not the benefit of his matured opinion on the geology of this area. Apart, however, from the general question of the true nature of the main mass of the Darling Range granites, further information on which will be found in the section on Later Acid Rocks, the following occurrences of probable metamorphosed sediments in the Western Province may be noted:

At Northampton (Maitland, 1903) is a strong development of gneiss, mica-schist and quartz schist, in places garnetiferous, which may be of sedimentary origin. Near Moora (Blatchford, 1912) occur quartzites cut by greenstones which also cut the granite. Woodward (1912*c*) and Montgomery (1909) indeed, respectively regarded them as Mesozoic and late Palæozoic, but, judging from their relation to the greenstones, they would certainly seem to be Pre-Cambrian. Near Mogumber, where a staurolite schist occurs (Simpson, 1921), and again at Mooliabeenee, Mr. G. S. Compton and myself have noted gneissic and schistose rocks, the field-characters of which indicate a sedimentary origin.

Possibly here should be placed a series of highly metamorphosed sediments reported to occur south of Toodyay, and also the schists north of Toodyay (Maitland, 1899) and at Wongan Hills (Maitland, 1899).

Along the front of the Darling Range at Armadale, Cardup and other places (Honman, 1912) is a narrow band of quartzite and phyllite bordered on both sides, and possibly invaded, by epidiorite. Saint Smith (1912) considers it to be a part of the Donnybrook-Collie Permo-Carboniferous rocks, nipped-in in the parallel system of faults which constitutes the "Darling Fault." Contact-metamorphic effects are, however, reported to occur in these shales and quartzites and this, if confirmed, shows that they must be older than the epidiorites. On the other hand there is some evidence in support of the view that the phyllites are merely excessively sheared zones in epidiorite dykes and that the "quartzites" are really great quartz reefs. The true nature of the Armadale belt of rocks, close to Perth, is a problem awaiting solution.

In parts of the North-West Province occurs a series, called the Warrawoona Beds, consisting essentially of greenstone schists of various types, both basic and ultra basic, originally (Maitland, 1908) regarded as being not only the oldest rocks in the areas in which they outcrop but also as being metamorphosed sediments.

One would therefore be inclined to regard the Warrawoona Beds as contemporaries of the Yilgarn Series of the country farther south. However, Professor Sir Edgeworth David and Dr. E. S. Simpson have lately examined typical exposures of the Warrawoona Series, and Dr. Simpson informs me that they both agree that the Warrawoona Series is identical lithologically with the sheared greenstones (styled the Kalgoorlie Series in this address) of the Central Province.

It seems more likely that certain other rocks in the North-West Province are metamorphosed sediments and are to be included in the Yilgarn Series: such are the rocks between the Wooramel and Arthur rivers and at Bangemall and Station Peak (Maitland, 1909, Woodward, 1911) which are said to be sediments metamorphosed to quartz and mica schists, marble, etc., and cut by both granite and greenstone—the latter at Bangemall being identical petrologically with the gold-bearing greenstones of the Central Province.

In the East Province, near Mt. Aloysius, there is apparently (Talbot and Clarke, 1917) a considerable development of highly metamorphosed sillimanite schists, quartzites, etc. The relation between these rocks and the regional gneisses of the area has not been determined, so that their position in the Pre-Cambrian sequence is quite unknown, but, from their lithological resemblance to rocks of the Yilgarn Series in other parts of the State, they may tentatively be placed here in the sequence.

B.—Kalgoorlie Series.

This term, used by Honman (1916), is convenient in that the series is typically developed at Kalgoorlie and, at nearly every gold-mining centre, is the "country" of the gold-bearing lodes which the word "Kalgoorlie" naturally suggests. It is indeed applied by Maitland (1919) only to the sedimentary facies of the series, but, despite the danger of confusion arising from the use of the term with two significations, I have not been able to think of any other nearly as apt.

The series consists of a metamorphosed set of more or less contemporaneous basic, intermediate and acid lavas, dyke rocks and pyroclastics. The basic facies consists mainly of metamorphosed dolerites, basalts and gabbros with local ultrabasic developments. These rocks are frequently termed diorites in the older geological reports, and the name has survived in everyday language, but the only recorded occurrence of true diorite is at Tampa (Farquharson in Jutson, 1917, p. 39). The basic facies is widely distributed throughout the State (as already remarked in the section on the relation between granite and greenstone), and is very important economically; it has therefore been more studied and consequently more subdivided than other portions of the series.

At Kalgoorlie, Feldtmann (1916) found that the oldest rocks of the series are the "older greenstones"—which are probably metamorphosed lavas. He found no evidence of the existence of pyroclastics which are strongly developed in other parts of the State. Probably a little later than these are the rocks of White Cliff quarry, which he considers to be sheared porphyrites. We may note here that at Gibraltar a porphyrite occupies the same relative position in the sequence (Blatchford, 1913). Apparently cutting these ancient lavas is a somewhat later series of metamorphosed basic rocks—the younger greenstones—which were probably injected as one great dyke in which differentiation went on after intrusion. The extreme of this differentiation is found in the peridotites and their derivatives. Feldtmann states, however, that the evidence favouring the distinction between newer and older greenstones is scanty. Metamorphosed sediments, to which little attention has been given, occur, apparently near the top of the series, but Feldtmann disagrees with Honman's (1916) diagnosis of the graphitic schists of Kalgoorlie as metamorphosed sediments. Detail regarding the succession at Kalgoorlie is readily obtained from the valuable bulletin (Feldtmann, 1916) already quoted. In this bulletin will also be found references to important papers, some of which, such as Larcombe's * and Thomson's, † are not listed in Section VIII.

A very similar sequence has been found in the country south of Kalgoorlie where there is, however (Honman, 1916), a large development of sediments, and of an acid facies of igneous rock.

Again in the Norseman district Campbell (1906) found that the oldest rocks are amphibolites interbedded with sandstones and conglomerates, which, being earlier than the quartz veins, are probably comparable with the sediments of the Kalgoorlie series at Kalgoorlie, despite their comparatively unaltered character.

The same general features in the Kalgoorlie Series have also been recognised in the Monger-St. Ives district (Clarke, X3) although no clear evidence of the existence of two sub-series of greenstones was obtained. Both here and at Bulong (Feldtmann, 1919) there is a much greater development of the porphyrite member of the series than at Kalgoorlie.

In the Southern Cross greenstone belt there is apparently no representative of the porphyrites and sediments of the Kalgoorlie series (the important metamorphic sediments of this area have been placed in the older Yilgarn Series) except indeed that Honman believes that here, as in other regions studied by him (for example Yerilla—Honman, 1917), the jasper bars are bands of contempor-

* Larcombe, C. O. G.; The Geology of Kalgoorlie. Australasian Institute of Mining Engineers, Melbourne, 1913.

† Thomson, J. A.; The Petrology of the Kalgoorlie Goldfield. Quart. Journ. Geol. Soc., Vol. LXIX., 1913, p. 621.

aneous sediments (Blatchford & Honman, 1917, p. 158). Blatchford, however, considers the jasper bars studied by him to be crush zones in the foliated greenstones, and it may be noted further that, in the country immediately north of the Yerilla District and on jasper bars continuous with those mapped by Honman, the features stressed by him (1917, p. 23) as evidence of the sedimentary origin of the jasper bars could not be recognised with certainty (Clarke, X1).

Near Rothesay, in the Yalgoo Goldfield, the greenstones have an exceptionally basic aspect, and at Melville they exhibit many peculiarities owing apparently to refusion of the greenstone by the later granite (Clarke, X2).

In the northern part of the Central Province the Kalgoorlie Series is represented mainly by basic igneous rocks in which older and younger greenstones cannot be distinguished.. Much attention, for example, was given both by Mr. Farquharson and myself to the various members of the Kalgoorlie Series at Meekatharra (Clarke, 1916) where, except for a small development of porphyrite, the basic igneous is the only facies represented, and we concluded that all the greenstones, which we subdivided rather elaborately according to the degree and character of their metamorphism, are derived from a common magma and that there is no evidence in the district of two ages of greenstone. The ultrabasic members of the group here, as in other parts of the State, are probably segregations from the doleritic magma and not separate intrusions.

In the north-eastern part of the Central Province there occurs a great belt of greenstones in which no subdivision on the score of age has been effected except in one or two remote and unimportant localities (Clarke, X1). The most marked characteristic of this region is the abundance of porphyrites, quartz porphyries, and rhyolites more or less contemporaneous with the ordinary greenstones. Thus, in the Leonora-Duketon District (Clarke, X1) is a development of rocks which were originally porphyrite and andesite flows and agglomerates, but which are now much altered in character. In one place the ordinary greenstones clearly cut the porphyrites. Somewhat similar rocks occur at Yilgangi (Honman, 1917) where, however, they are regarded as younger than the greenstones. Probably also the porphyritic greenstone of Mt. Ida and Sir Samuel (Gibson, 1907) is another development of the porphyrite facies. At Ora Banda (Jutson, 1914 *a*) porphyrite occupies the central part of the field, and is most likely derived from the same magma as the normal greenstones.

Again, a marked development of a still more acid phase of the Kalgoorlie Series is found between Duketon and Tampa. In Bulletin 84 (Clarke, X1) these rocks are described (see also Clarke, 1919) and some evidence is adduced for regarding them as con-

temporaneous with the greenstones and distinctly older than the intrusive granite. Mr. Farquharson suggests that they are the counterpart of the fuchsitic slaty porphyries of the "Golden Mile" and of a rock occurring as lenses in granite about seven miles east of Paddington (Feldtmann, 1915, p. 124). Similar rocks occur in widely scattered localities, for example: at Menzies (Woodward, 1906, and Clarke, 1919, p. 19), where is found a fuchsite andalusite schist; at Warrawoona (North-West Province), where occurs an andalusite rock which Simpson (Maitland, 1908, p. 156) regards as a metamorphosed felspar porphyry; at Goongarrie (foliated quartz porphyries, Jutson, 1921); at Payne's Find (Goodingnow) (Clarke, X2); at Kanowna, where some of the country originally described as sedimentary rocks more or less metamorphosed (Blatchford and Jutson, 1912) is stated in a later publication (Jutson, 1914 *d*) to be sheared quartz porphyry; at Gibraltar, the divergent views regarding which area have been noted under the Yilgarn Series; in the Norseman district, where Campbell (1906) notes the occurrence of quartz porphyries sheared to sericite schist (I have noted the same at Widgiemooltha and in the Monger-St. Ives district (Clarke, X3)). In the Norseman and Monger-St. Ives district the finer-grained acid and intermediate Pre-Cambrian rocks are divisible into older sheared, which may be classed with the Kalgoorlie Series, and younger unsheared. It may well be, however, that in many localities—for example, Kunanalling (Gibson, 1908), Cue (Woodward, 1914), Kurnalpi (Jutson, 1914)—this shear-structure is not necessarily an indication that the rocks affected are the older Pre-Cambrians, for it may have been produced in the later granitic rocks, during their intrusion which took place during a period of mountain building. The same explanation also may be advanced for Honman's gneissic granites (see further under Granite).

Metamorphosed rhyolites, no doubt the volcanic phase of the foliated quartz porhpyries just described, have been recognised in the Tampa area (Jutson, 1921) in the Yerilla District (Honman, 1917) and a little farther north near Melita (Clarke, X1).

In the Kalgoorlie Series we have the altered products of a long period of intense igneous activity which ensued when the first-formed acid shell cracked and to some extent foundered in the more basic substratum with consequent squeezing out of some of the basic magma. The basic was mixed with smaller quantities of more acid rock formed by the melting of portions of the acid shell. This period of igneous activity was a long one and obviously the lavas, tuffs, etc., of the earlier part of the period would be cut at different times by dykes originating from the same magma. During subsequent periods the whole series was metamorphosed into its present state. It seems, therefore, that the evidence obtained in different parts of the country regarding the occurrence of more than one age of greenstone must always be conflicting.

C.—Mosquito Creek Series.

In the North-West Province is found a large development of a series of sediments younger than the Kalgoorlie, but nevertheless somewhat metamorphosed, which are earlier than the granites and are gold-bearing. These are typically developed in Mosquito Creek, a tributary of the Nullagine River (Maitland, 1919, p. 17).

In dealing with the Yilgarn Series the possibility that some of the metamorphic sediments of this region are older than the Kalgoorlie Series and were laid down in Yilgarn times has been mentioned.

Regarding the Pre-Cambrian geology of the Kimberley Province we have as yet very little detailed information. It may be noted that Jack (1906) regards the granites seen by himself as the ultimate stage of metamorphism of the sedimentary "Silurian, Cambro-Silurian, or Cambrian" rocks, which being "metamorphic slaty schistose and gneissic rocks, carrying the auriferous bodies" of the area might belong either to the Kalgoorlie or to the Mosquito Creek Series. Dr. Simpson, however, informs me that all the rocks which he has seen from the gold-producing regions of the Kimberley are lithologically like the Mosquito Creek rocks and do not resemble the greenstones of the Kalgoorlie Series.

In the other provinces there are scattered occurrences of rocks best assigned to this place in the Pre-Cambrian sequence.

Woodward (1912) gave the rocks of this character occurring in the Peak Hill Goldfield the distinctive name of Gascoyne Series. Montgomery (1910, p. 61, and 1920) described them as metamorphosed sediments of later age than the Kalgoorlie Series and contemporaneous with the Mosquito Creek Series proper.

Talbot (1920) described rocks of similar character occurring in various places between longitudes 119° and 122° E. and latitudes 22° and 28° S. He nowhere, however, found the granite intrusive into these rocks. He classed the series as younger than the granite, thus assigning it to a horizon different from that given it elsewhere by other observers.

In the West Province also are several occurrences of metamorphosed rocks which, on available evidence and until more is known about the relative ages of the granites in different parts of the State, might almost equally well be classed with the Yilgarn or with the Mosquito Creek beds. Considering their generally advanced state of metamorphism they seem more appropriately placed in the older series, and a brief description of their distribution and content will be found under the Yilgarn Series. However, Woolnough (1920) concludes that the very striking exposure of quartzites, slates, quartz schists and mica schists in Stirling Range which are cut by granite and also by epidiorite may most reasonably be assigned to Mosquito Creek times.

In the Central Province, in the Warriedar district, metamorphosed sediments carrying auriferous and other ore-bodies at Yandhanoo Hill (Maitland, 1915, 1916, 1923, p. 36) and near Warriedar (Feldtman, 1921) appear to fall into this place in the sequence, though possibly they belong to the older Yilgarn Series. A band of metamorphosed conglomerate near Mt. Dennis (Talbot, 1920, p. 6) is also to be regarded as an outlier of the Mosquito Creek Series.

Honman's Kurrawang Series (1916 & 1914, p. 23), a set of somewhat metamorphosed sediments characterised mainly by strong development of conglomerates containing fragments of rocks of the Kalgoorlie Series, must also be grouped with the Mosquito Creek Series.

Scattered occurrences of somewhat metamorphosed coarse fragmental rocks in the East Province between the Warburton Range and the South Australian border (Talbot and Clarke, 1917, p. 94) may also belong to Mosquito Creek times.

D.—Later Acid Rocks.

A large part of the State is mapped as "Granite and Gneiss" (Maitland, 1919), also in nearly every mining centre are bars of acid rock intrusive into the Kalgoorlie or Mosquito Creek Series.

1. *Granite.*—The bulk of the "Granite and Gneiss" seems to come in this place in the Pre-Cambrian succession. No detailed systematic study of the Western Australian granites as a whole, or even of the granites of one area has yet been undertaken.

Many years ago Simpson (1909) defined at least three types of granite in the State; one barren of minerals of value, the second associated with ores of tin and tantalum, the third with ores of gold and copper. Dr. Simpson informs me that he still recognises these types and finds that the first is a microcline granite, the second a soda granite, the third a granodiorite. Mr. R. A. Farquharson, petrologist of the Geological Survey, has in conversation expressed the opinion that there are two main types of granite in the West and Central Provinces—a yellowish granite containing very little ferro-magnesian mineral (what there is being mainly biotite) and a greyish white biotite granite. Although one is struck by the number of recorded occurrences of hornblende granite, it may be that, as suggested by Woodward (1914) and Jutson (1921, *a* & *b*), the hornblende replaces the biotite by some endomorphic process near contact with the intruded rock, or as the result of slight dynamic metamorphism.

The main mass of the granite of the East, unlike that of the Central Province which is sheared mainly or solely along its margin, is, so far as known, a regional gneiss, consisting of large quartz and microcline crystals and a little hornblende. This rock neverthe-

less (Talbot & Clarke, 1917, pp. 90, 92) grades into great porphyry dykes which cut greenstones identical lithologically with those of the Kalgoorlie Series of the Central Province. The occurrence of charnockites (Farquharson—Talbot & Clarke, 1917, pp. 159-61) appears to be unique in this State. The abundance and size of the fresh gabbro and dolerite dykes which cut the granite of the East Province are noted in Section IV.

In the Central Province all observers agree that where the granite and the Kalgoorlie Series are in contact the granite is intrusive. It is only gneissic either along its contact with the older rocks or in restricted areas within the main body of the rock. The gneissic structure is thought to be due, partly to drag along contact with the intruded rock and partly to earth-movement during the mountain-building period which was responsible for the granite intrusion.

Probably the late Mr. H. P. Woodward devoted more attention than any other field-geologist to the characteristics of the Central Province granites. In the northern part of the Yilgarn Goldfield (1912) he distinguished hornblende-biotite granite, albite-muscovite granite, and orthoclase-biotite granite. The first and second he regarded as possibly metamorphosed sediments. In part of the Murchison Goldfield, centring round Cue, he (1914) found that a hard porphyritic muscovite granite intrudes the biotite granite which forms the bulk of the country and which cuts the greenstones of the Kalgoorlie Series. At Cue and Cuddingwarra he (1907) noted an exceptional granodioritic type which at Cue carries the chief auriferous bodies. Granodiorite is also known to occur at Kookynie, where Jutson (1921*a*, p. 38) regards it as a "magmatic variation of the granite."

At Meekatharra (Clarke, 1916) two varieties of the biotite-microcline granite have been recognised—the Southern Cross type, which has a prevalent yellow-brown colour, and carries pegmatites and some gold and copper deposits, and the Meekatharra type, which normally bears distinct signs of dynamic strain, and, though not itself ore-bearing, is probably the parent of the various porphyry dykes which in turn have a close connection with the chief gold-bearing bodies of the district.

The granite at Warriedar is unusually acid, being composed of quartz, oligoclase microcline and muscovite in varying proportions (Feldtmann, 1921).

Honman (Blatchford & Honman, 1917, p. 149, Honman, 1914, 1916, 1917) believes that in various parts of the Central Province the normal granite encloses patches of an older gneiss which is possibly a relic of the ancient basement on which the greenstones were deposited. However, in the country immediately north of the Yerilla district in which Honman found these older gneissic granites

and in several other parts of the Leonora-Duketon district (Clarke, X1) field and microscope evidence combine to show that the gneissic patches are merely local variations of the great granite batholith.

Gibson (1906) recognised two ages of granite near Burtville, but I have not been able to find any evidence in the field to support this view.

A problem awaiting final solution is that of the relationship of the hornblende-biotite gneiss, which so far has only been found at Westonia (Blatchford and Honman, 1917, p. 56) and at Payne's Find or Goodingnow (Clarke, 1920 & X2), that is at two mining centres near the western edge of the Central Province. At both places the hornblende-biotite gneiss carries auriferous bodies and is thought to owe its strongly gneissic character to lit-par-lit injection of quartz into a granodiorite. Field-work at Goodingnow led me to believe that the gneiss was formed by the injection of a belt of the epidiorite by a great number of pegmatite dykes, but this conclusion was not supported by detailed petrological work. Whether the original granodiorite was an acid segregation of, or an intrusion into the greenstone (in which latter case it would have an analogy in the granodiorites mentioned already) is not yet quite definitely settled, though Blatchford (1917, p. 56) holds strongly to the latter view.

It is very likely that, as detailed work is done on granite areas, patches of older rock will be discovered, just as rocks formerly mapped as granitic as Quinn's (Gibson, 1904) and Leonora (Jackson, 1904) have been shown afterwards (see section on Yilgarn Series) to be probably metamorphosed sediments.

In the West Province Aurousseau's work (1916) at Albany and at Roelands near Bunbury shows how much has yet to be done before we are in a position to generalise safely regarding the composition of the granite areas. At Albany the oldest rock is gneiss, in places garnetiferous, which is intruded by granodiorite. Later than both of these is microgranite. At Roelands, on the other hand, the gneiss has been produced from granodiorite very similar to the later rock at Albany.

The question of the possibly sedimentary origin of the West Province gneisses has already been raised in dealing with the Yilgarn Series. There seems to be general agreement that in the south-west part of the Province the gneiss has been formed by the shearing of an acid igneous rock which is, as already remarked, a granodiorite porphyry at Roelands. In this part the trend of the gneiss is apparently fairly regular (*e.g.*, Greenbushes—Feldtmann, 1914, p. 156, Bridgetown—Maitland, 1899, p. 23, Goomalling—Maitland, 1899).

In the Darling Range near Perth the acid rocks are in the main massive though in places (for example Darlington) the granite has been converted, along narrow zones, into quartz-sericite schist.

In the north part of the West Province (Campbell, 1910) east of the apparent continuation of the Darling Fault (Suess, 1906) are found granitic rocks of gneissic aspect. These gneissic rocks are well shown for example close to the fault-contact with Permo-Carboniferous rocks at Badgerer pool on the upper Irwin River.

A broken belt of gneiss lies west of the Darling Fault. In this belt the gneiss seems to be everywhere garnetiferous (between Capes Naturaliste and Leeuwin—Saint Smith, 1912, near Northampton—Feldtmann, 1920, p. 15, near Arrino and Mingenew—Campbell, 1910) and in the northern part carries lead and copper lodes. At Albany (which, however, lies too far east to be included in the belt just described) Aurousseau, as already noted, distinguishes an older gneiss which is intruded by granodiorite very like that of Roelands. Possibly the garnetiferous gneiss of the Leeuwin-Northampton belt is an older rock than the main body of granite, granodiorite and gneiss.

In the North-West Province granite is intrusive into the Mosquito Creeks beds and Maitland (1909) is inclined to distinguish two ages of granite near Roebourne. A granodioritic phase occurs at Mosquito Creek (Simpson, 1916, p. 20).

No detail regarding the Kimberley "granites" is available except Jack's opinion regarding their sedimentary origin which has been noted under the Mosquito Creek Series.

It is evident even from this imperfect summary that there are many unsolved problems regarding the Western Australian granites, but it may be suggested that the "granite and gneiss" of the most recent geological map of the State, include rocks of at least two very different ages. In the East and West Provinces some of the gneisses may be highly metamorphosed sediments, inextricably mixed with remnants of the first earth-shell of acid composition. In the Central Province the granite is in the main rejuvenated earth-shell, fused by deep burial and folding and thrust up, as great batholiths among the Yilgarn, Kalgoorlie, and Mosquito Creek rocks.

2. *Acid Dykes—apophyses of the granite.*—In almost every mining centre of the Western Australian Goldfields occur acid dyke rocks intrusive into the gold-bearing (Kalgoorlie or Mosquito Creek) series. The opinion has been expressed by many observers that these dykes, though few are themselves auriferous, have a close connection with the origin of the lodes or veins, and that, though comparatively few can be traced into the granite, they are really offshoots from that rock. The acid dykes vary in coarseness of grain and somewhat in mineral composition, but it seems, judging from the more exact petrological determinations made of late years, particularly by Dr. J. A. Thomson and Mr. R. A. Farquarson, that the dykes most commonly associated with auriferous

bodies are albite porphyry and albite granite. There is some conflict between this statement and Dr. Simpson's opinion quoted previously that soda granites are associated rather with ores of tin and tantalum, granodiorite being the companion of gold deposits.

3. *Porphyrite Dykes.*—These are apparently a series distinctly younger than the porphyrites which form part of the Kalgoorlie series. So far they have been noted almost solely in the country at Kalgoorlie and, farther south, at Bulong where Feldtmann (1919) distinguishes a series of porphyrite and porphyry dykes younger than his series of porphyrites and porphyrite breccias, and in the Monger-St. Ives district where a similar sub-division of the porphyrite rocks was made independently (Clarke X3).

4. *Latest Acid Intrusions.*—In nearly all the granite areas of the State occur pegmatite veins cutting the granite and all earlier rocks. Probably, however, these pegmatites are not much younger than the granite which they intrude, being merely the ultra-acid residual matter of the granite magma which was forced into the cracks formed in the cooling mass of granite.

However, it appears that, at least in the Western Province, pegmatites of two ages occur. In the majority of places, *e.g.*, Greenbushes (Feldtmann, 1914) near Goomalling (Jutson, 1912), between Capes Naturaliste and Leeuwin (Saint Smith, 1912) the pegmatite dykes are intrusive into the epidiorite dykes which in turn are intrusive into the granite, whereas at Boya, near Perth, small epidiorite dykes cut the pegmatites, and at Albany, Aurousseau (1916) distinguishes an earlier epidote-biotite pegmatite from a later series of pegmatites.

E.—Nullagine Series.

The "Nullagines" are basic igneous flows and pyroclastics with conglomerates, quartzites, sandstones, grits, shales, limestones and dolerites. The distribution and character of the main areas of this series, which are found in the Kimberley and North-West Provinces, are described by Maitland (1919) and Simpson (1923). In the Central and West Provinces, in addition to the outliers of the series mentioned by Maitland (1919) several other occurrences of unmetamorphosed rocks, uncomformably overlying all the series described above, may, lacking more definite evidence, be classed as Nullagine. Thus, as well as the "ancient sediments and associated igneous rocks" of Mt. Singleton and the horizontally bedded rocks of Mt. Yagahong (Clarke, 1916, p. 72) and other places assigned by Maitland (1919) to this series, we might include in it the gently inclined beds of lava,* pyroclastics and sediments of Billeranga Hills; the exactly similar quartzoze conglomerates underlain by basic volcanics which form a

* One of which, Dr. Simpson informs me, is a much weathered orthoclase dolerite.

prominent escarpement at "Granite Hill," near Yandanooka; the tuffs, sandstones and conglomerates of Three Springs (Feldtmann, 1919); and the uncrushed quartzites and conglomerates of Mt. Jackson Range (Blatchford and Honman, 1917, p. 161).

The scattered areas of metamorphosed sediments found in the Central and West Provinces are placed, according to the intensity of their metamorphism, either with the Yilgarn or with the Mosquito Creek Series.

The suggestion is made by Talbot (1920) that certain fine-grained amphibolised and zoisitized dolerites which probably cut the Kalgoorlie Series in the North-West Province are of the same age as the lavas forming part of the Nullagine Series. One would be tempted therefore to correlate with these the epidiorite dykes cutting the granites, etc., of the West Province, but, since the epidiorites have suffered considerable dynamic metamorphism, while the supposed Nullagine amphibolised and zoisitised dolerites of the West Province are not metamorphosed, this is hardly possible. Nevertheless, it would be well worth while to determine definitely the relationship of epidiorites and "Nullagines" in the West Province, and, for such an investigation the neighbourhood and Billeranga Hills appears well suited.

Attention may be drawn to the fact that while Talbot (1920) considers the Carawine limestones to be Post-Carboniferous, Maitland (1919, p. 28) places them in the Nullagines.

Finally, it may be said with regard to the Nullagine Series that the question of its inclusion in the Pre-Cambrian Group is in doubt. As the result of work in the East Province, Mr. Talbot and myself were led (1917, more detail in 1918, see also Maitland, 1919, p. 27) to suggest that the series is of Ordovician age. Although the evidence is not very strong, it is at present a little more convincing than that on which a Pre-Cambrian age is assigned to the series.

VI. Unmetamorphosed Basic Dykes.

Reference must be made to the ubiquitous series of later unmetamorphosed basaltic dolerite dykes and larger masses of gabbro and norite. These rocks form prominent surface features in the East Province (Talbot and Clarke, 1917), in the North-West Province (Talbot, 1920), and in the Central Province (Norseman District, Campbell, 1906, and Clarke, X3; Barloweerie Peaks, Clarke, 1916). In the Central Province they are also found in mine-workings in many places where no sign of their presence can be detected at the surface (Talbot and Clarke, 1917, footnotes, p. 99). An unusual type from Kalgoorlie and St. Ives has recently been described by Farquharson (1923). In age these rocks are probably Mesozoic or Tertiary (Clarke, 1916, p. 64, and Talbot, 1920), but they are so

commonly found intrusive into the Pre-Cambrians that no description of the group, however brief, would be complete without mentioning them.

VII. Summary.

It is quite unnecessary after what has been said in the preceding part of this paper to stress the fact that the classification suggested makes no pretence at finality. The paper will, however, be of use if it directs the attention of our geologists to some unsolved problems of importance in the ancient rocks of our State.

I suggest then that our "Pre-Cambrian" rocks comprise the following series, beginning with the oldest:—

A. *Yilgarn Series.*—Occurring in comparatively small patches amongst younger Pre-Cambrian rocks. Chiastolite, andalusite, mica and other schists—largely of sedimentary origin, also gneisses, some of sedimentary, some of igneous origin, probably remnants of first (acid) earth-shell.

B. *Kalgoorlie Series.*—Occurring in the Central, North-West and East Provinces in numerous island-like patches in the much larger area of granite. Predominantly basic igneous rocks metamorphosed to epidiorites, etc. Minor developments of ultra-basic and acid igneous and of sediments. Probably intrusive into Yilgarn Series.

C. *Mosquito Creek Series.*—Main development in North-West Province. Sediments, metamorphosed, but not so strongly as those of the rocks of the older series. Clearly younger than Yilgarn and Kalgoorlie Series.

D. *Later Acid Rocks.*—Most extensively developed portion of the whole Group. Predominantly granite—in some places gneissic. Younger than any of preceding series as judged by character of its contact with them, yet probably includes patches of much greater age.

E. *Nullagine Series*—but possibly Ordovician—sediments and basic igneous flows and dykes not affected by regional metamorphism. Youngest series of epidiorite dykes—which has greatest development in West Province—can only be a little older than the Nullagines.

I suggest also that the "Pre-Cambrian" areas of the State may be divided into the following "Provinces"—four of which are known to have distinctive characteristics:—

East Province.—Regional Gneisses. Charnockites. Great dykes of unaltered basic rocks, which are younger than any of the epidiorites. East and West trend of greenstones belts.

Central Province.—Maximum development of Kalgoorlie Series with general N.N.W. trend. Almost entire absence of youngest series of epidiorite dykes.

West Province.—Maximum development of youngest epidiorite dykes. Strong development of massive and gneissic granite.

North-West Province.—Maximum development of Mosquito Creek and Nullagine Series, East and West trend-lines marked, N.N.W. trend-lines also represented.

Kimberley Province.—Characteristics unknown.

I have purposely avoided all attempt at correlation with other Pre-Cambrian regions.

VIII.—Bibliography.

The following list of papers quoted in this contribution is not a complete bibliography of the Pre-Cambrian geology of Western Australia. Some papers which marked most important advances in the knowledge of the subject, such as Simpson's* and Thomson's,† will not be found here, because the conclusions stated therein have been generally accepted and are now common knowledge. I have included in the list three reports by myself, which, like several other bulletins, have been awaiting publication for two years and more. I have done this, because I believe the areas described in those reports display the true character of the older part of the group and because it was field work in them which enabled me to form some opinion regarding the order of succession in the Pre-Cambrian rocks.

Titles of papers are much shortened, and, besides ordinary contractions, the following abbreviations are used:—

A. Annual Progress Report of the Geological Survey of Western Australia for the year........

B. Geological Survey of Western Australia, Bulletin No.......

Aurousseau, M.	**1916**	Western Australian gneissic and granitic rocks. Proc. Linn. Soc. N.S.W., Vol. XLI., Part 2, p. 261.
Blatchford, T.	**1912**	Possibilities of artesian water near Moora. B. 48, p. 56.
	1913	Burbanks and Londonderry. B. 53.
	1917	Graphite at Munglinup. B. 76.
	1919	Asbestos East of Moora. A. 1918.
Blatchford, T., and Jutson, J. T.	**1912**	Kanowna. B. 47.
Blatchford, T., and Honman, C. S.	**1917**	Yilgarn Goldfield, Part III. B. 71.
Campbell, W. D.	**1906**	Norseman. B. 21.
	1910	Arrino-Northampton. B. 38.

* Simpson, E. S.; "Notes from the Departmental Laboratory," p. 62; "Rocks of Kalgoorlie," Western Australia. Geol. Survey. Bulletin No. 6.

† Op. cit.

Clarke, E. deC. ...	... 1916	Meekatharra. B. 68.
	1919	Leonora-Duketon and Menzies. A. 1918.
	1920	Goodingnow, Rothesay, and Noongal. A. 1919.
	1921	Monger-St. Ives. A. 1920.
	x1	Leonora-Duketon. B. 84 (not yet published.)
	x2	Goodingnow, Rothesay, and Noongal. B. 86. (Not yet published.)
	x3	Monger-St. Ives. B. 90. (Not yet published.)
Farquharson, R. A.	... 1923	Olivine Picrite at Kalgoorlie. Journ. and Proc. Roy. Soc. of W.A., Vol. IX. Part I., p. 23.
Feldtmann, F. R.	... 1914	Kapanga Mine, Greenbushes. B. 59, p 56.
	1915	Mulline, etc. B. 64, p. 133.
	1916	Kalgoorlie. Part III. B. 69.
	1919	(*a*) Bulong. B. 82.
		(*b*) Clay at Three Springs. A. 1918.
	1920	Clay at Bolgart. A. 1919.
	1921	(*a*) Northampton. A. 1920.
		(*b*) Quinn's and Jasper Hill. B. 80.
		(*c*) Warriedar. B. 81.
	1922	Gibraltar. A. 1921.
	1923	Youanmi. A. 1922.
Gibson, C. G. ...	... 1904	Part of Murchison Goldfield. B. 14.
	1906	Laverton, Burtville and Erlistoun. B. 24.
	1907	Lawlers, Sir Samuel, Darlot, Mt. Ida. B. 28.
	1908	Bonnievale, Kunanalling, and Black Range. B. 31.
	1909	Transcontinental Railway route. B. 37.
Honman, C. S. ...	... 1912	Kelmscott Clay. B. 48, p. 63.
	1914	(*a*) Bremer Range. B. 59, p. 190.
		(*b*) Kalgoorlie-Coolgardie. B. 56.
	1915	Mt. Jackson-Koolyanobbing. A. 1914.
	1916	Country South of Kalgoorlie. B. 66.
	1917	Yerilla, B. 73.
Jack, R. Logan ...	... 1906	Artesian Water in Kimberley. B. 35.
Jackson, C. F. V.	... 1904	Leonora. B. 13.
Jutson, J. T. ...	... 1912	Darling Plateau. B. 48, p. 138.
	1914	(*a*) Ora Banda. B. 54.
		(*b*) Kurnalpi, B. 59, p. 13.
		(*c*) Yuin. B. 59, p. 140.
		(*d*) Further Notes on Kanowna. B. 59. p. 215.
	1917	Golden Butterfly Mine. B. 74.
	1921	(*a*) Kookynie, Niagara, and Tampa. B. 78.
		(*b*) Comet Vale and Goongarrie. B. 79.
Maitland, A. G. ...	... 1899	Wongan Hills, Blackboy Hill, Bridgetown, etc. A. 1898.
	1903	Northampton. B. 9.
	1908	Pilbara Goldfield. B. 40.
	1909	Parts of Peak Hill, Gascoyne, and Ashburton Goldfields. B. 33.
	1910	Leonora. A. 1909, p. 14.
	1916	Mt. Singleton and neighbourhood. A. 1915, p. 6.
	1917	Mt. Singleton and neighbourhood. A 1906, p. 9.

Maitland, A. G.	1919	Summary of Geology of Western Australia. Geol. Surv. of W.A., Memoir No. 1, Chapter I.
	1919	Gold Deposits of Western Australia. Geol. Surv. of W.A. Memoir No. 1, Chapter II., Part III. Section I.
Montgomery, A.	1908	Quartz Reefs at Wagin. Report of Department of Mines, of W.A. for 1907, p. 91.
	1909	Guano near Watheroo. Report of Department of Mines of W.A. for 1908, p. 66.
	1910	State of Mining in certain centres in Murchison and Peak Hill Goldfields. Department of Mines of W.A.
	1902	Manganese at Horseshoe. Government Printer, W.A.
Montgomery, A. and Maclaren, M.	1914	Phillips River Mines. Department of Mines of W.A.
Saint-Smith, E. C. ...	1912	South-West Division. B. 44.
Simpson, E. S.	1909	Types of W.A. Granite. A. p. 7.
	1916	Analyses of W.A. Rocks, etc. B. 67.
	1921	Staurolite from Mogumber. Journ. and Proc. Roy. Soc. of W.A., Vol. VII., p. 71.
	1923	Sulphates and Chert in Nullagine series. Journ. and Proc. Roy. Soc. of W.A., Vol. IX., Part 2.
Suess, E.	1906	The Face of the Earth. English translation. Vol. II.
Talbot, H. W. B. ...	1920	(*a*) Zanthus to Laverton. A. 1919. (*b*) South part of Yalgoo Goldfield. A.1919. (*c*) Parts of North-West, Central and Eastern Divisions. B. 83.
Talbot, H. W. B., and Clarke, E. deC.	1917	Laverton to South Australian Border. B. 75.
	1918	Expedition to South Australian Border. Jour. and Proc. Roy. Soc. of W.A., Vol. III., p. 70.
Woodward, H. P. ...	1895	Mining Handbook of W.A. Second Edition, Perth, Government Printer.
	1906	Menzies. B. 22.
	1907	Cue and Day Dawn. B. 29.
	1908	Greenbushes, etc. B. 32.
	1909	Phillips River Goldfield. B. 35.
	1911	West Pilbara Goldfield. B. 41.
	1912	(*a*) North part of Yilgarn and South part of North Coolgardie Goldfields. B. 46. (*b*) Country at heads of Gascoyne and Ashburton Rivers. B. 48. (*c*) Watheroo. B. 48, p. 22.
	1914	Part of Murchison Goldfield. B. 57.
Woodward, H. P., and Blatchford, T.	1917	Kendenup Graphite. B. 74, p. 95.
Woolnough, W. G. ...	1920	Stirling Ranges. Journ. and Proc., Roy. Soc., N.S.W., Vol. LIV., p. 79.

IX.—Location of Places mentioned in Text.

After each locality is put, first its approximate south latitude, second its approximate east longitude. Location of a goldfield is to about its middle, of a river to its mouth.

I am greatly indebted to Mr. A. Gibb Maitland, Government Geologist, for permission to attach uncoloured prints of the Geological Map of Western Australia.

Albany 35°, 117° 50.
Armadale 32° 10, 116°.
Arrino 29° 30, 115° 40.
Arthur River 25°, 115° 25.
Ashburton Goldfield 22° 50, 115° 30.
Badgerer Pool 28° 50, 115° 40.
Bangemall 24°10, 116° 50.
Barloweerie Peaks 26° 45, 118°.
Billeranga Hills 29° 20, 115° 50.
Bolgart 31° 20, 116° 30.
Boya 31° 50, 116° 10.
Bridgetown 34°, 116° 10.
Bullfinch 31°, 119° 10.
Bulong 30° 40, 121° 40.
Bunbury 33° 20, 115° 40.
Burtville 28° 45, 122° 40.
Canning River 32°, 115° 40.
Cape Leeuwin 34° 20, 115° 10.
Cape Naturaliste 33° 30, 115°.
Cardup 32° 15, 116°.
Collie 33° 20, 116° 10.
Comet Vale 29° 55, 121° 10.
Condon 20°, 119° 30.
Coolgardie 30° 55, 121° 10.
Corunna Downs 21° 30, 119° 50.
Cuddingwarra 27° 20, 117° 50.
Cue 27° 25, 118°.
Darling Range 31° 30, 116° 10.
Darlington cp. Boya.
Derby 17° 20, 123° 50.
Donnybrook 33° 30, 115° 50.
Duketon 27° 40, 122° 10.
Eenuin 30° 45, 119.
Eramurra Creek 21°, 116° 15.
Forrestania 32° 30, 119° 50.
Gascoyne Goldfield 24° 20, 116° 20.
Gibraltar 31°, 121°.
Goodingnow 29° 15, 117° 40.
Goomalling 31° 20, 116° 50.

Goongarrie 30° 05, 121° 10.
Greenbushes 34°, 116°.
Irwin River 29° 15, 114° 50.
Kalgan River cp. Albany.
Kalgoorlie, 30° 45, 121° 30.
Kanowna 30° 35, 121° 30.
Kendenup 34° 30, 117° 40.
Kookynie 29° 20, 121° 30.
Kunanalling 30° 40, 121° 05.
Kurnalpi 30° 30, 122° 10.
Leonora 28° 50, 121° 20.
Marvel Loch 31° 30, 119° 40.
Meekatharra 26° 35, 118° 25.
Melville, *see* Noongal.
Menzies 29° 40, 121°.
Mingenew 29° 10, 115° 25.
Mogumber 31°, 116° 05.
Monger 31°, 121° 50.
Mooliabeenee 31° 20, 116° 10.
Moora 30° 40, 116°.
Mosquito Creek 21° 50, 120° 30.
Mount Aloysius 26°, 128° 30.
Mount Dennis 29°, 122° 50.
Mount Ida 29° 15, 120° 25.
Mount Jackson 30° 15, 119° 20.
Mount Kenneth 29°, 118° 10.
Mount Samuel 24° 20, 116° 30.
Mount Singleton 29° 30, 117° 20.
Mount Yagahong 26° 50, 118° 35.
Murchison Goldfield 26° 50, 117° 30.
Noongal 28° 10, 116° 45.
Norseman 32° 10, 121° 50.
Northampton 28° 20, 114° 40.
Nullagine 21° 50, 120° 15.
Ora Banda 30° 20, 121°.
Paddington 30° 30, 121° 20.
Parker Range 31° 40, 119° 20.
Payne's Find, *see* Goodingnow.
Peak Hill Goldfield 24° 55, 117° 40.
Perth 32°, 115° 50.
Phillips River Goldfield 33° 10, 120°.
Pilbara Goldfield 21°, 119° 30.
Quinn's 27°, 118° 35.
Ravensthorpe 33° 30, 120° 10.
Roebourne 20° 40, 117° 10.
Roelands 33° 15, 115° 45.
Rothesay 29° 15, 116° 50.
Sandstone 28°, 119° 20.


The Hon. J. Scaddan M.L.A. Minister for Mines
GEOLOGICAL SKETCH MAP
OF
WESTERN AUSTRALIA.
BASED ON THE WORK OF THE GEOLOGICAL SURVEY.
A. GIBB MAITLAND
GOVERNMENT GEOLOGIST.
1920
Scale of English statute miles
REFERENCE
Towns ... shown thus ... EUCLA
Railways
Land District Boundaries
Land Division
Goldfields
Telegraph Lines & Stations
Lighthouses
Stock Routes
Heights in feet
Steamer Routes
KIMBERLEY DIVISION
NORTH WEST DIVISN
EASTERN DIVISION
SOUTH WEST DIVISN
EUCLA DIVISN
INDIAN OCEAN
THE GREAT AUSTRALIAN BIGHT
SOUTH AUSTRALIA
ARCHIPELAGO OF THE RECHERCHE
Longitude 121° East of Greenwich
Geology compiled by F.R. Feldtmann
LEGEND.
CAINOZOIC
Tertiary and Post-Tertiary Coastal limestones, Fortescue River Beds, alluvium, etc.
MESOZOIC
Cretaceous
Jurassic and undifferentiated Cretaceous
Permo-Carboniferous and Carboniferous
PALÆOZOIC
Devonian
Ordovician
Cambrian
Nullagine
Mosquito Creek and Stirling Range Beds (Auriferous rocks in places)
PROTEROZOIC
ARCHÆOZOIC
Undifferentiated metamorphic rocks (Auriferous rocks in places)
IGNEOUS
Granite and gneiss
Porphyries and porphyrites
Basalt
Dolerite dykes and sills
Gabbro dolerite, epidiorite, serpentine etc.

Simon Hill 31° 50, 123°
Sir Samuel 27° 35, 120° 30.
Southern Cross 31° 10, 119° 20.
Station Peak 21° 10, 118° 10.
Stirling Range 34° 20, 117° 45.
St. Ives 31° 20, 121° 50.
Tampa 29° 15, 121° 30.
Three Springs 29° 35, 115° 50.
Toodyay 31° 30, 116° 30.
Wagin 33° 20, 117° 25.
Warburton Range 26°, 127°.
Warrawoona 21° 25, 120° 20.
Warriedar 29° 10, 117° 05.
Westonia 31° 20, 118° 45.
West Pilbara Goldfield 21° 10, 116° 25.
Widgiemooltha 31° 30, 121° 35.
Wongan Hills 30° 50, 116° 35.
Wooramel River 25° 50, 114°.
Yalgoo 28° 20, 116° 40.
Yalgoo Goldfield 28°, 116°.
Yandanooka 29° 30, 115° 40.
Yandhanoo Hill 29° 30, 117° 15.
Yerilla 29° 30, 121° 45.
Yilgangi 29° 45, 122° 10.
Yilgarn Goldfield 30° 20, 119°.
Yuin 28°, 116°.
Zanthus 31°, 123° 35.

THE STRUCTURE OF THE SIDEREAL UNIVERSE.

By ROBERT TRUMPLER, Assistant Astronomer, Lick Observatory.

(Being the substance of an address delivered on 8th August, 1922.)

As a result of new discoveries in the sciences related to Astronomy, such as Mathematics or Physics, or of the construction of various instruments of greater observing power, different branches of Astronomy have at different times engaged the attention of astronomers. During the last decade, interest has been centred in the problems connected with the structure and constitution of the sidereal universe, *i.e.*, in the physical properties of the fixed stars, their evolution, and their distribution in space.

The important and unexpected results recently brought forward in this connection are due to the successful accomplishment of the most difficult task confronting astronomers for more than half a century—I mean the measurement of the distances of the fixed stars. In the case of a star relatively near the earth, the distance may be determined by what is known as the trigonometric method. When the Sun is about 90° away from the star in the sky, the position of the star, as compared with a number of very distant faint stars surrounding it, is accurately measured. After six months, when the earth is at the opposite side of its orbit, the observation is repeated, and it is found that the star has apparently shifted slightly among the distant faint stars. From the amount of this shift, termed the *parallax*, the distance of the star may be deduced. Stellar distance is too great to be conveniently measured in miles, and hence the astronomer uses as a unit the "light year," or the distance which light would travel in one year. (One light year is equal to 5,870,000,000,000 miles.)

For most stars the parallax is exceedingly small and difficult to measure; it is like observing a shift of ½ inch at a distance of 20 miles. It is only during the last 15 years, with the aid of the largest modern telescopes and with the use of photography, that considerable progress has been made in these delicate measures. Six of the larger American observatories, together with the Greenwich Observatory, devote a great part of their time to this problem. At the present moment we have reliable measures of the distances of about 1,000 stars, and their number is rapidly increasing. Unfortunately the stars of the southern constellations cannot be reached by these observatories, and only for very few southern stars are the distances known. This is a serious handicap in studies on the structure of the sidereal universe, and astronomers are anxious that some observatory situated in the Southern Hemisphere be equipped with a large refractor and take up this line of work. Australia with its excellent observing conditions would have here an opportunity to make a very valuable contribution toward the advancement of human knowledge.

The method for measuring stellar distances outlined above gives reliable results only for the nearer stars, up to a distance of about 100 light years; for more distant objects the shift produced by the annual motion of the Earth around the Sun becomes too small to be measured with any degree of certainty. For penetrating farther into space we have to resort to more indirect methods. Before we enter on these, however, let us see what information about the constitution and the physical properties of the stars we obtain from the distance measures of those stars that are nearer than 100 light years. The stars, like the Sun, are big gaseous masses rendered highly luminous by their enormous temperatures (3,000° to 20,000°). There is no essential distinction between the Sun and a star; the Sun is just one among the many million stars of which the sidereal universe is composed; it is that peculiar star in whose planetary system we are living. To the astronomer it seems not only possible, but even probable, that other stars also have their planetary systems. The stars appear so much fainter to us than the Sun simply because of their incomparably greater distance. But even the stars among themselves appear very different in brightness, and we naturally inquire what factors produce this inequality in the apparent brightness. Comparing a bright star with a faint one, we may find that they actually send out the same amount of light, but that one of them appears fainter because it is farther away from us. On the other hand, we may find a pair of stars of dissimilar appearance which are at the same distance from us; in this case the two stars must be different in their actual luminosity. Popularly speaking, we may say that one of them has a higher candle power, and that the two stars appear to us like an arc lamp and a candle light seen at the same distance. We can observe directly only the apparent brightness of a star, which depends as we have seen, not only on its distance, but also as on its real luminosity; but if its distance is known, we can easily calculate the luminosity. One of the most important results in the measurement of stellar distance is that it gives us information about the luminosities of the nearer stars. In this way we find that the stars cover an enormous range of luminosity, some being over a million times as luminous as others, even if seen at the same distance.

In order to understand this unexpected result, we have to study the constitution of the stars more closely, and to take into account the observations obtained by means of the spectroscope. The starlight that reaches our instruments is a mixture of vibrations of different duration. The human eye roughly classifies these different vibrations as colours. When the light of a star passes through a prism of glass, the vibrations of different duration are separated, the light is spread into a band of colours which we call the spectrum, and this spectrum allows a careful analysis of the starlight. The colour band of a star is generally interrupted by numerous narrow

dark lines. These so-called "spectral lines," representing isolated vibrations, are characteristic of the chemical elements of which the source of light is composed, or of the material through which the light is passing. An extensive spectroscopic study of about 200,000 stars has just been completed at the Harvard Observatory. This great piece of work is giving evidence of two important facts, first that the stars are composed of the same chemical elements which we know on the Earth, for only very few spectral lines cannot be identified and may be due to unknown elements, and secondly, that although the stellar spectra do not all show the same appearance, yet they can all be classified according to a few characteristic types. These spectral types with intermediate gradations form a continuous series. They seem to represent different stages in the evolution of the stars. While each star during its life history passes through approximately the same stages of evolution, the stars which we observe are not equally advanced in their development: some are "younger," others "older." Accompanying a change in the spectral type there is also a change in the colour of the star from bluish-white to white, yellow, orange and red.

Experiments in the physical laboratory have shown that a body is the more luminous the higher its temperature, and that at the same time the colour of the total light emission changes slightly from the red towards the blue. Therefore our spectral types represent different degrees of temperature, ranging from about 3,000° for the red stars to about 20,000° for the bluish-white stars. We should now naturally inquire if the large range in the luminosities of the stars is not in some way related to the temperatures and to the spectral types. Such an investigation made for the stars of known distance led Hetzsprung and Russell to the surprising result that the luminosities of the stars are indeed closely related to their spectral types, but that we have to divide the stars into two classes, viz., *"giant"* and *"dwarf"* stars. The high luminosity of the giant stars is about the same for all spectral types and temperatures, while the luminosity of the dwarf stars is very low for the red stars of relatively low temperature, but increases rapidly for the higher temperatures. The two classes of stars join each other in the bluish-white stars of high temperature, but are widely separated in the red stars of low temperature.

Let us compare for example a red giant star like *Antares* with a red dwarf star like that discovered a few years ago by Barnard through its rapid motion, and generally known under the name of Barnard's star. *Antares* is of first magnitude, Barnard's star appears 2,500 times fainter; but from parallax measures we find that it is also 40 times nearer to us than *Antares*. In reality, therefore, it must be four million times less luminous than *Antares*. What is the cause of this enormous difference of luminosity between the two stars that show about the same type of spectrum, and should be at

nearly the same temperature? There remains only one explanation—a giant star like *Antares* must have a much larger surface, diameter, and volume than a dwarf star such as Barnard's star. This conclusion has recently found a brilliant confirmation, when the astronomers of the Mount Wilson Observatory in Southern California actually succeeded in measuring the diameter of *Antares* with a new instrument (the interferometer), and found it to be about 300 times as large as that of the Sun.

We should expect a giant star having so large a volume to be in proportion more heavy and massive. This, however, is decidedly contradicted by our information about the masses of the stars, meagre though it is. It is only possible to determine the individual masses of stars in cases of double stars, where two stars are close enough to each other to produce a sensible gravitational attraction, causing them to follow an orbital motion around their common centre of gravity. For a limited number of such binary stars the data necessary to calculate the masses are known, but all the results so obtained indicate that the masses of the stars vary only within a small range. We are thus led to the conclusion that giant and dwarf stars both contain a similar amount of matter; in a dwarf star this matter is concentrated in a small sphere, while in a giant star it is very tenuously distributed throughout an enormous volume. The density of matter prevailing on the average in a red giant star like *Antares* is low beyond imagination; it is rather less than one thousandth of the density of our atmosphere at sea level, and is only comparable with the density in a vacuum tube with less than 1 mm. mercury pressure.

As to the evolution of a star, it had been supposed until about 10 years ago, that a star during its lifetime passed once through the series of spectral types as the temperature decreased. The discovery of the giant and dwarf division among the stars introduced an unexpected complication, and led to a modification of this hypothesis. A star, according to this new theory of evolution, starts its life history, as far back as we can follow it, as a red giant star of relatively low temperature with an enormous volume and an exceedingly tenuous distribution of matter. In the stage of the red giant stars our Sun must have occupied a sphere extending beyond the present orbit of the planet *Mars*. Gravitation and radiation produce a gradual contraction, thus diminishing the volume and increasing the density and the temperature of the star. The giant star is passing through the different spectral types in the direction of higher temperatures until it reaches the stage of the white or bluish-white stars, where a turning point is reached. On account of the higher density the contraction is slowing down. The thermal energy gained by this contraction is no longer in excess of, nor even equal to the heat lost by radiation (increased by the high temperature). The star is beginning to cool, it has become a dwarf star and is again

passing through the different spectral types, but this time in the direction of diminishing temperature. During its stages as a giant the star is nearly constant in luminosity, as the effect of smaller surface is about balanced by the increasing intensity of radiation per surface unit due to the higher temperature. As a dwarf, the star is very rapidly decreasing in luminosity; diminishing surface and decreasing intensity of radiation are both working together to reduce the amount of light sent out by the star. This continues until the star becomes too faint to be observed with our telescopes. Thus, if we classify all stars according to their volume (or density) instead of temperature, giant and dwarf stars from the two ends of one continuous series of increasing density passing twice through the series of observed spectral types.

It is interesting to note that the most recent researches in stellar evolution have led us to a theory that is entirely in harmony with the fundamental ideas of Laplace's Nebular Hypothesis set up over a century ago. Laplace tried to explain the formation of our planetary system by a gradual contraction of the Sun from a big nebulous body of low density (comparable to a red giant star) to its present size.

While the measures of the parallaxes of the nearer stars form the basis on which the theory of the giant and dwarf stars is built, this theory, once established, can now be applied to gain information about the distances of more remote celestial objects. If the spectral type of a star is observed, and if it is possible to decide whether the star is a giant or a dwarf, then our theory will give us immediately its luminosity, *i.e.*, its brightness if seen from the distance unit (33 light years). Measures of the apparent brightness of the star will tell us how much fainter it appears to us and how many distance units it must be away.

The most difficult part of this method is to separate the giant and dwarf stars. Dr. Adams at the Mount Wilson Observatory has found that a giant and a dwarf star of the same general spectral type differ in their spectra just by the intensity of a few lines. Careful observations of these spectral lines make it possible, if the star is not too faint for its spectrum to be photographed on a suitable scale, to determine directly its luminosity and to derive from its apparent brightness the distance (spectroscopic parallax).

The method of determining stellar distances from the spectrum and the apparent brightness is not only applicable to individual stars (even very faint ones, if the colour is used instead of the spectrum), but it has also given valuable information about the distances of star clusters and nebulæ (if stars are involved in these). Take for example the star cluster of the *Pleiades*. Most of the brighter stars in this group show motion in the same direction with equal speed, and they form a well defined system with common origin. Seen from

the Earth this system appears projected on the celestial sphere together with many other stars, some of them nearer, most of them more remote than the *Pleiades*. By means of their common motion, however, it is possible to pick out the stars which are physical members of the *Pleiades* system from those which simply form the "background." Among these *Pleiades* members, for example, we find a star of 10th magnitude to be a dwarf star showing the same spectral type as our Sun. Hence we conclude that it has the same constitution and luminosity as the Sun. Having then measured how much fainter the star appears to us than the Sun, we can calculate how much farther it is away from us. Another *Pleiades* star of magnitude 7.5 resembles in its spectrum the near bright star *Sirius*, of which the parallax has been measured. A comparison of the apparent brightness of the *Pleiades* star with that of *Sirius* gives again a determination of the distance of the *Pleiades*. From a number of such comparisons the *Pleiades* group is found to be situated at a distance of 327 light years. Most of the other star clusters of the Milky Way are still more remote, and for some of the densely crowded globular clusters values as large as 100,000 light years are indicated by this method.

Other lines of research of a more statistical nature have also contributed largely to the knowledge of the structure of our stellar universe. I shall mention only the method of counting the numbers of stars that exceed different limits of brightness, and the study of the motions of the stars, which on the average must appear smaller the farther they are away. From all results bearing on this subject we come to the conclusion that the stars seen or reached with the telescope form a limited system, and that the Sun is situated not very far from its centre. This system, having approximately the shape of a flat lens, contains over a thousand million stars, and the Milky Way, or Galaxy, is an essential feature of it. It is for this reason that we call it the Galactic System. The plane of the lens coincides with the plane of the Milky Way, and the reason we find so many faint stars in the clouds of the Milky Way is that in this direction our system extends much farther, *i.e.,* we look through a greater depth. In other directions the limit of the system is nearer to us, and we find the fainter stars less numerous.

There is still considerable uncertainty about the dimensions of the Galactic System—estimates of its diameter ranging from 30,000 to 300,000 light years. Star clusters and nebulæ seem to belong to this system, especially to the more distant parts of the Milky Way. There is only one class of objects, the spiral nebulæ, which many astronomers believe to lie outside the Galactic System. Their spectrum resembles that of star light and suggests that these objects are composed of stars; that they are island universes similar to our own stellar universe, but situated at distances of millions of light years. It should however be mentioned that this view cannot yet be con-

sidered to be well established, and that much controversy on this point is going on at the present time.

Knowledge of stellar distances is one of the most important requirements for the understanding of the structure of the sidereal universe. Remarkable as is the progress made during the last decade in establishing our knowledge of these distances on a more accurate and reliable basis, much work still remains to be done in applying the methods recently developed to a larger number of and to more remote celestial bodies.

SECONDARY SULPHATES AND CHERT IN THE NULLAGINE SERIES.

By Edward S. Simpson, D.Sc., B.E., F.C.S.

Read 13th March, 1923.

1.—The Nullagine Series.

The series of rocks which constitute the Nullagine Formation of A. Gibb Maitland is one of the most important groups of rocks in the whole State of Western Australia, covering as it does not less than 60,000 square miles of country in the north-western part of the State, and reaching a thickness of at least 1,500 feet. This formation consists mainly of horizontal or slightly dipping shales and sandstones with subordinate dolomites and normal limestones. At various points round the eastern and south-eastern edge conglomerates have been observed, whilst towards the northern boundary coarse conglomerates and interbedded lavas and tuffs are developed extensively. Throughout the area covered by the series there are frequent dykes and sills of dolerite, whilst on hill tops cherts and ferruginous laterites are notable features. The beds form in part an immense plateau (peneplain), the remnants of which constitute the Chichester, Hamersley-Ophthalmia, Lofty, Collier and Barlee-Capricorn-Waldberg Ranges, and the highest point in which is Mt. Bruce with an elevation of 4,000 feet. The broad flat valleys formed by the advanced dissection and deflation of this plateau are also, according to H. W. B. Talbot, almost all occupied by Nullagine beds as, except round the extreme borders of the formation, erosion has not reached to the base of the series, and as yet there is no evidence of later sediments of any appreciable extent having been deposited in them, except possibly in the upper Fortescue Valley.

The geological age of the Nullagine beds has not yet been fixed with certainty. No fossils have been found in them, though many of the shale beds are more or less highly carbonaceous, some being in fact quite black in colour, indicating the contemporaneous existence of living organisms. Furthermore, thin limestone beds and concretions of both calcite and marcasite are widespread, and in the genesis of these living organisms often play an important part.

Our estimate of the age of the formation has therefore been based upon evidence other than palæontological, viz.:—

(a.) Structural relationship to other large formations.
(b.) Nature of pebbles included in the conglomerate beds.
(c.) Nature of igneous intrusions.
(d.) Presence of metalliferous veins.
(e.) Extent of structural and chemical change.

The Archæozoic system is represented in the North-West by the Warrawoona igneous schists referable to the Keewatin; and by the Strelley, Minilya, and Murchison granites, referable to the Laurentian. Overlying these unconformably are the Mosquito Creek-Ashburton series of meta-sediments—phyllites, psammites and siliceous conglomerates—the latter, in the Pilbara Goldfield, made up largely of pebbles of Warrawoona jasper. This series is referable to the Huronian. The Nullagine series overlies all three other series, and shows at most points of contact a marked unconformity with the Mosquito Creek beds. The conglomerates of the Nullagine series near Nullagine itself have been found to enclose boulders of Mosquito Creek phyllite and jasper conglomerate, of Warrawoona greenstone schists, of Strelley River granite, and of various intrusive rocks. In regard to the upper limits of the formation, H. W. B. Talbot considers that on the east side in the vicinity of the Paterson and Broadhurst Ranges there is evidence of the Nullagine beds being overlaid unconformably by the South Kimberley Carboniferous.

There is no evidence of the Nullagines being intruded by the pegmatites, acid porphyries or peridotites which are so abundant in the Warrawoona series. On the other hand, intrusive dykes and sills of quartz dolerite are common throughout the series, though they are not known to traverse the Carboniferous anywhere in this region.

Veins of quartz are rare and always small in the Nullagines, though abundant and sometimes of immense size in the three underlying series. Furthermore, whilst the Warrawoona and Mosquito Creek-Ashburton rocks are highly metalliferous, with numerous workable lodes of gold, silver, copper and lead, the Nullagine beds are notoriously poor in these metals. No lead or silver has been recorded from them, and primary gold has been found in only four places, viz., Nullagine, Sunday Hill, Rooney's Patch, and Just in Time. In all four cases the gold occurs in the basal beds of the Nullagine close to auriferous areas of Mosquito Creek or Warrawoona rocks. Copper, which is widespread in the Warrawoona and Mosquito Creek Series, has been found only in small quantities in the Nullagines and at few localities, the only areas of any commercial importance being Kumerina and Ilgarere.

Over immense areas the Nullagine beds are still horizontal or dip at angles less than 25 degrees. Locally, however, A. Gibb Maitland and H. W. B. Talbot have noted sharp folds with dips up to 70°. Of deep seated chemical change there is no evidence, such typical metamorphic minerals as andalusite, garnet, tourmaline, staurolite, etc., being totally absent. The kaolin of the shales has certainly in part been sericitised, but nowhere to the extent of giving the rock the appearance of a mica schist. This micacisation can take place, and in this case has undoubtedly taken place, at no great depth and without any unusual increase of pressure or temperature.

To summarise: our present knowledge indicates that the Nullagine beds are post-Huronian and pre-Carboniferous, and are later that the main metallogenetic epoch in Western Australia. Further, they are not greatly metamorphosed structurally and chemically, and belong to an age in which advanced living organisms were not abundant. The evidence available points to their being of Keeweenawan, Cambrian, or Ordovician Age, probably the first named, though Talbot prefers to correlate them with the Ordovician of South Australia.*

II.—Nature and Distribution of Sulphates.

The occurrence of secondary sulphates in Nullagine sediments was first brought under the author's notice by specimens of pickeringite and copiapite sent by a prospector from Glen Ross on the Upper Ashburton River. Later the author detected jarosite in several specimens of the auriferous conglomerate from Nullagine, and at various times and localities members of the Geological Field Staff noted gypsum in the Nullagine series. The widespread distribution of such minerals in this formation was, however, first forcibly impressed upon the author during a flying trip made in 1921 with Sir Edgeworth David from Meekatharra to Marble Bar. On this journey the main Nullagine area was traversed completely from north to south, and two days were spent at the type locality. In addition to observing gypsum and epsomite in several places, alunite was detected for the first time in the series in a gully (Alunite Gully) in the Chichester Range between Roy Hill and Bonnie Downs Stations, and with it jarosite. Since then alunite and jarosite have been found at Millstream Station, 200 miles further west in the Fortescue Valley. Finally an efflorescence, consisting of a mixture of pickeringite and tamarugite, sent in recently by a prospector from the Upper Gascoyne is doubtless derived from the Nullagine beds, which cover most of the country in that area.

* G. S. W. A. Bull. 83, p. 150.

The complete list of secondary sulphates noted is:—

Normal Sulphates—

Gypsum, $CaSO_4.2H_2O$.
Epsomite, $MgSO_4.7H_2O$.
Tamarugite, $Na_2Al_2(SO_4)_4.12H_2O$.
Pickeringite, $MgAl_2(SO_4)_4.22H_2O$.

Basic Sulphates—

Copiapite, $Fe_4O(SO_4)_5.18H_2O$.
Alunite, $KAl_3O_3(SO_4)_2.3H_2O$.
Jarosite, $KFe_3O_3(SO_4)_2.3H_2O$.

III. Nature and Distribution of the Chert.

H. W. B. Talbot writes* of the eastern section of the Nullagine region:

> ". . . . The upper stratum on the tops and on the slopes of the ranges and hills composed of sedimentary rocks is indurated by the deposition of silica brought upwards in solution by capillarity, and, owing to the hard and brittle nature of this rock, it is highly susceptible to induration."

Talbot refers† frequently to the indurated cherty capping to the Collier and Lofty Ranges, and to the presence at times of a similar induration of the slopes of the ridges. On the other hand, in the Hamersley-Ophthalmia Ranges "the indurated capping is everywhere ferruginous, and there is a marked absence of the silicification of the faces of cliffs, so common in the gorges of other plateaus."‡ In the ridges about Deadman's Hill, between the Lofty and Ophthalmia Ranges Talbot notes the prevalence of "jaspers" (banded ferruginous cherts) forming part of the Nullagine Series. The low "Chalcedony hills," found at intervals on the Upper Fortescue Plain, are possibly identical formations,§ but other jasperoid rocks in the Hamersley-Ophthalmia Ranges, are associated with intrusive rocks, and are evidently of the nature of porcellanites. Much further to the east Talbot describes a brecciated chert forming a surface layer of considerable extent above the junction of the Oakover and Davis Rivers.‖

Talbot describes the cherts mainly *in situ* on the tops or slopes of ridges, but the writer's attention was first drawn to their wide distribution by the frequent "gibber plains," thickly strewn with angular "gibbers," *i.e.*, pebbles and boulders, of chert which occur to the north of the triple junction of the Upper Gascoyne River.

* G. S. W. A. Bull. 83, p. 21. † Idem pp. 42-46. ‡ Idem p. 47. § Idem p. 98. ‖ Idem p. 111.

A typical example may be seen at Batthewmurnana Hill, a high butte of Nullagine sediments capped with a 10 to 15 foot crust of chert, boulders of which are thickly strewn on the steep slopes of the butte and on the plain round its base. It is evident that this detrital chert is the result of the lateral erosion of the butte, wind and water having scattered abroad all the softer granules of the shales and sandstones underlying the chert cap.

Twenty miles to the northeast, at Kumerina, the low undulating foot hills of the Collier Range are thickly strewn with chert "gibbers," and are underlain in at least one place (Mineral Lease 37) by gypseous shales.

In the gorges, on the south face of the Chichester Range, a little north of Roy Hill Homestead, the tops of all the spurs are composed of a thick bed of chert, below which, in "Alunite Gully," alunite, jarosite, epsomite, and gypsum are somewhat abundant. At Millstream, shale partly altered to chert has been found close to oxidised pyrite nodules and jarosite veins.

Near Stock Route Well, No. 49, on a plateau below the crest of the Chichester Range, areas of chert are again seen on the surface.

Numerous other localities might be cited, but the examples given illustrate the wide distribution of this chert; its constant occurrence *in situ* as a ridge or plateau capping, or more rarely as a coating on the slopes of ridges of Nullagine sediments; its frequent appearance as angular boulders in the talus slopes and spread over the plains; and its definite association in several places with secondary sulphates.

This chert in hand specimens is a very dense, microgranular rock, containing over 90 per cent. of silica, banded more or less perfectly in structure, and with banded or mottled colouring, varying from dull yellow, through shades of brown to black. Microscopically, it is found to consist mainly of chalcedony, with a little vitreous quartz, mica, and a carbonate in isolated granules. No trace of siliceous organisms has been detected in any of the thin slices. In mass in the ridge cappings the rock is usually distinctly cavernous, dense rock alternating with roughly lenticular cavities of all sizes.

Chert has also been found in Alunite Gully as a complete replacement of calcareous concretions in shale, and, in intimate admixture with limonite, as a replacement of rounded marcasite-pyrite nodules.

IV.—Source of the Sulphates.

The immense quantities of gypsum found throughout the physiographic province known as the Dry Lake Area, have been considered

by the writer to be due to the evaporation of cut-off areas of a Tertiary ocean retreating to the south or south-east. This ocean appears to have covered an area, roughly, extending between the present south coast and lat. 28°S., and between longs. 117° and 130°E., the exact shoreline at the time of maximum invasion being, of course, quite irregular. One of the strongest arguments in favour of this origin, apart from the discovery of Miocene sponges on both sides of the Stirling Range and as far inland as the extreme north end of Lake Cowan, is the close association of the gypsum deposits with salinas, the subsurface water of which closely resembles an evaporated ocean water. Three examples of this will suffice:—

Subsurface Water from Salinas, Dry Lake Region.

——	Lake Monger, Wubin Downs.	Lake Goongarrie,* Comet Vale.	Lake Cowan, Norseman.
	%	%	%
$CaCO_3$	·004	·002	·008
$CaSO_4$	·136	·133	·224
$MgSO_4$	2·765	2·153	1·132
$MgCl_2$	4·374	2·994	3·190
KCl	·970	·038	·074
NaCl	24·251	20·107	18·881
NaBr	·023	*Nil*	not det.
$NaNO_3$	*Nil*	*Nil*	*Nil*
SiO_2, Al_2O_3, etc.	·005	·030	·004
	32·528	25·457	23·513

* From shaft half mile from lake.

The overwhelming proportion in these waters of common salt and the large amounts of magnesium sulphate and chloride, all typical cyclic salts, point to their being beyond all doubt ocean residuals. Further it is to be noted that all the well waters throughout this area give evidence of this absorption of ocean water by the weathered rocks below a fairly definite contour line ranging between 1,000 and 1,500 feet above present ocean level.

No similar evidence is presented by the dry area* covered by the Nullagine series in the North-West Division of the State. Subsurface and surface waters even in low-lying and arid areas are for the most part fresh or only brackish, and in the latter case

* Most of this region has a rainfall under 10 inches per annum.

the constituent solids do not point to any direct relationship with ocean water. Typical examples of these waters are:

Subsurface Water from Nullagine Region.

—	Town Well, Nullagine.	Homestead Well, Ethel Creek.	S.R. Well 41, Mundiwindi.	Copper Mine, Kumerina.
	%	%	%	%
$FeCO_3$	·0002	trace	trace	trace
$CaCO_3$	·0171	·0142	·0155	·0202
$MgCO_3$	·0305	·0329	·0080	·0105
Na_2CO_3	...	·0099	...	...
$CaSO_4$	...	...	...	...
$MgSO_4$	·0633	...	·0144	·0307
Na_2SO_4	·0708	...	...	...
K_2SO_4	·0227	·0036	·0031	·0042
KNO_3	...	·0139	...	...
$NaNO_3$	not det.	...	·0055	trace
$MgCl_2$	...	...	...	...
KCl	not det.	·0101	·0040	·0006
NaCl	·1700	·0025	·0334	·0337
SiO_2	·0025	·0064	·0050	·0014
Al_2O_3	·0009	·0008	·0004	·0008
Total solids ...	0·3780	0·0943	0·0893	0·1021*

* Also trace of copper carbonate.

The Nullagine sediments were probably marine, but they are so ancient and so well dissected and drained that the greater part of the originally associated ocean water might well be expected to be washed out of them. The absence of potential $CaSO_4$ and $MgCl_2$ from the tabulated waters, and the low content in NaCl of nearly all of them show that they are not of the marine type. Further the presence of alkali sulphates in minerals found in the Nullagine rocks, and of potential alkali sulphates in the waters indicates a predominance of the sulphate ion never found in ocean waters. Finally, certain of the sulphates now found in the sediments have never been recorded as constituents of marine salt beds such as those of Alsace or Germany. The compounds referred to are the alums, tamarugite and pickeringite, and the basic sulphates, alunite and jarosite.

After due consideration of all the circumstances of their occurrence the conclusion is reached that, in the absence of any indication of fumarole action, the sulphates must originate in the oxidation of marcasite and pyrite occurring in the sediments, and to a lesser extent in the associated lavas. Small quantities of pyrite are a primary product of consolidation of the lavas which are widespread in the Chichester Ranges, and further north. In some places these have suffered considerable oxidation, but as a rule they are very dense and fresh. At Nullagine, Kumerina, and

possibly at a few other points metalliferous veins in the Nullagine Series carry pyrite and other sulphides. These give rise to sulphates in the immediate vicinity but only account for a minor portion of the whole. On the other hand concretions of marcasite and pyrite are found at many points embedded in carbonaceous shales, and over a wide area pseudomorphs of limonite after these sulphides have been found in situ in the shales and loose in the talus slopes and creek beds.

For many years past specimens have reached Perth from the North-West consisting of limonite (micogranular goethite) pseudomorphs after cubes and round concretions of iron sulphide. These have now been seen *in situ* in several localities, and unaltered and partly altered concretions of sulphide have been collected at Millstream Station and elsewhere.

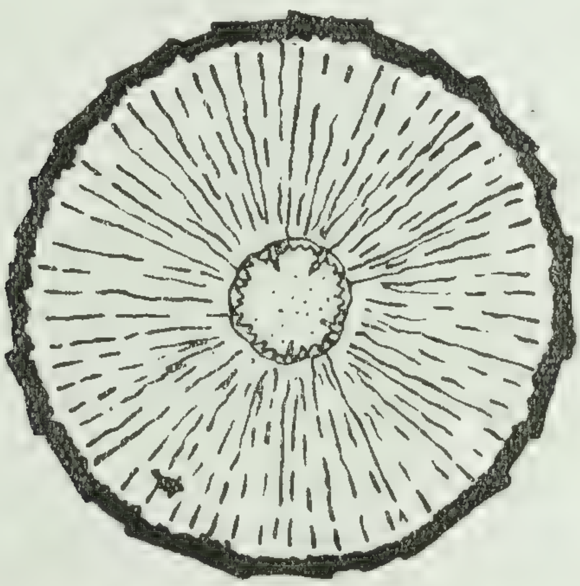
The sulphide concretions from all parts of the region bear a very close resemblance to one another. They are mostly spherical in outline but not uncommonly ovoid or lenticular, and occasionally have a form suggesting the coalescence of several concretions which have grown from nuclei lying a little distance apart from one another. They vary in diameter from about 1 to 7 cm. (0·5 to 3·0 inches), and have a rather rough surface made up of small cube or octahedron faces. That they usually consist of three fairly distinct layers is evident even in fresh specimens, but is much more apparent in those which are partly or wholly altered to goethite (see fig. 1). The centre is a massive iron sulphide, which may be either marcasite or pyrite. It frequently contains a few granules or minute crystals of quartz and weathers to a porous mass which drops out when an oxidised concretion is split open. Encrusting this core is a thick layer of radially prismatic marcasite, which usually forms by far the major portion of the whole nodule. The surface is composed of a thin continuous crust of pyrite crystallised in cubes, or rarely octahedra (see fig. 1).

The matrices of these concretions are grey or black carbonaceous shales, possibly occurring at more than one horizon in any given section. One of the localities at which entirely unaltered concretions have been exposed by rapid lateral erosion, is Millstream Station on the Lower Fortescue, about one mile north-west of the homestead. There the matrix is a jet black thinly laminated shale. This locality has yielded the largest nodule yet seen, viz., 7 cm. in diameter with an attached satellite 3 cm. in diameter. The marcasite of this particular nodule was partly oxidised, and the surface pyrite showed numerous octahedron faces. Precisely similar sulphide nodules are known to occur at Tambrey Station about 30 miles east of Millstream, and A. Gibb Maitland has noted* that pyrite is abundant in shales at Broad Flat Well between Millstream and Tambrey.

* G.S.W.A. Bull. 33, p. 122.

A rough shapeless nodule with dense interior and pyrite faces on the surface has been collected at Mt. Florence Station, 20 miles further to the south-east. This may be composed wholly of pyrite. At Bulla Downs Station, south of the Ophthalmia Range, there are numerous small concretions in a grey shale. These are either subspherical or lenticular in form, and are composed of marcasite and pyrite like those found farther to the north-west.

Fig. 1.



Goethite Pseudomorph after Marcasite-Pyrite Concretion, Millstream Station.

The progress of erosion over most of this region is much more rapid laterally than vertically under recently existing conditions. Even laterally it is usually slower than the progress of subsurface oxidation, for which reason unoxidised concretions of iron sulphides are much less in evidence than are goethite pseudomorphs after them. Such pseudomorphs are reported to be especially plentiful on the West Pilbara Tableland, north of the Lower Fortescue. Here, and in many other localities, they are found still embedded in the Nullagine shales, or lying loose in stream beds or on the slopes of the deep gorges which penetrate the Nullagine peneplain. Other typical localities are Just-in-Time, west of Marble Bar; Millstream and Tambrey Stations on the southern scarp of the West Pilbara Tableland; Alunite Gully at the east end of the Chichester Range; and Balfour Downs Station near the head of the Oakover River.

V.—Chemistry of the Origin and Alteration of the Sulphides.

Pyrite and marcasite are quite common constituents of carbonaceous sediments of all ages. They are usually ascribed to the re-

duction of the water soluble sulphates to sulphides by inorganic or organic (bacterial) action, and the interaction of these sulphides with ferrous carbonate, which is always present when carbonaceous matter and ferric hydroxide come into contact. The reactions may be represented thus:—

$$(1.)\ Fe_2O_3 \cdot H_2O + 2C + 3O = 2Fe_2CO_3 + H_2O$$
$$(2a.)\ MgSO_4 + 2C + H_2O = MgCO_3 + H_2S + CO_2.$$
$$(2b).\ FeCO_3 + 2H_2S + O = FeS_2 + CO_2 + 2H_2O.$$

Marcasite is the principal sulphide formed when the medium is acid or neutral in reaction, pyrite when it is alkaline. Nodules with an inner layer of marcasite and an outer of pyrite indicate a change, during the period of growth, from neutral or acid to alkaline conditions, *e.g.,* by the superposition of beds of limestone, which, in several places are known to overlie the pyritic zone.

The first step in the normal oxidation of marcasite or pyrite, when brought by denudation within reach of atmospheric influence, follows the following equation:—

$$(3.)\ FeS_2 + H_2O + 7O = FeSO_4 + H_2SO_4.$$

This action produces two soluble sulphates whose migration and chemical activity lead to a long series of alterations in the associated sediments.

To trace the sulphuric acid first. Contact with a limestone, always in this district magnesian, and carrying small amounts of manganese and iron, the reactions which take place quite rapidly are—

$$(4.)\ CaCO_3 + H_2SO_4 + 2H_2O = CaSO_4 \cdot 2H_2O + H_2CO_3.$$
$$(5.)\ MgCO_3 + H_2SO_4 + 7H_2O = MgSO_4\ 7H_2O + H_2CO_3.$$
$$(6a).\ MnCO_3 + H_2SO_4 = MnSO_4 + H_2CO_3.$$
$$(6b).\ MnSO_4 + CaCO_3 + O + 2H_2O = MnO_2 + CaSO_4\ 2H_2O + CO_2.$$
$$(7a).\ FeCO_3 + H_2SO_4 = FeSO_4 + H_2CO_3.$$
$$(7b).\ 2FeSO_4 + 2CaCO_3 + O + 5H_2O = Fe_2O_3 \cdot H_2O + 2CaSO_4 \cdot 2H_2O + 2CO_2.$$

These equations indicate the final products of the action of sulphuric acid upon limestone to be gypsum, epsomite, pyrolusite, and goethite. At Alunite Gully (*vide infra*) such a series of minerals is actually associated with goethite pseudomorphs after iron sulphide modules, and chert pseudomorphs after calcite.

The action of the acid upon the shales immediately in contact with the nodules is equally interesting. These shales consist largely of muscovite, kaolin, and quartz. The last is unaffected by acid, but the other two are slowly attacked according to the following scheme:—

$$(8.)\ Al_2O_3 \cdot 2SiO_2 \cdot 2H_2O + 3H_2SO_4 = Al_2(SO_4)_3 + 2H_2SiO_3 + 3H_2O.$$
$$(9.)\ 2H_2O \cdot K_2O \cdot 3Al_2O_3 \cdot 6SiO_2 + 4H_2SO_4 + 6H_2O = 6H_2O.K_2O \cdot 3Al_2O_3 \cdot 4SO_3 + 6H_2SiO_3.$$

Equation (8) shows the formation from kaolin of solutions of aluminium sulphate, which in the presence of alkali or magnesium sul-

phates in the ground waters, would yield alums so long as the solutions are notably acid, and alunite or natroalunite, if they became only faintly acid or neutral. Were the solutions to come in contact with limestone, gibbsite would result, minerals of the alum and alunite series being unstable in the presence of even weak alkalis. Equation (9) shows the direct derivation of alunite from sericite.

The ferrous sulphate solution formed in the original oxidation of the marcasite or pyrite (equation 3) may, early in its career, be precipitated by limestone to form goethite according to equation (7b). In the absence of limestone, and the solution remaining acid, oxidation to ferric sulphate would be observed, thus:—

$$(10.)\ 2FeSO_4 + H_2SO_4 + O = Fe_2\,(SO_4)_3 + H_2O.$$

This oxidation reduces the acidity to one-half, and favours the tendency to form basic salts, a tendency still further increased by the neutralisation of part of the remaining acid by kaolin, etc. So long as the solution does not become alkaline there is a strong probability of copiapite being formed by hydrolysis:—

$$(11.)\ 2Fe_2(SO_4)_3 + 19H_2O = 2Fe_2O_3\cdot 5SO\cdot{}_318H_2O + H_2SO_4.$$

In the presence of alkalis in the ground water, jarosite or matrojarosite would result:—

$$(12.)\ 3Fe_2\,(SO_4)_3 + (K,Na)_2\,SO_4 + 12H_2O = 6H_2O.\ (K,Na)_2O.\ 3Fe_2O_3\cdot 4SO_3 + 6H_2SO_4.$$

We have thus accounted for the derivation of all the observed sulphates.

Equations (8) and (9) show the formation of soluble silicic acids during the oxidation of the pyrite nodules. This is of the greatest significance when considered in the light of the wide distribution of chert as a surface formation, not only the ridge and mesa tops but also on the slopes of the rises, as described by Talbot.

Attempts have been made from time to time to account for such cherts as the result of—

(1) Consolidation *in situ* of beds of opal of organic origin, viz., the skeletal remains of sponges, radiolaria, or diatoms.

(2) Formation by lateritic action from solutions of silica produced by the action of ground water of normal composition on underlying quartz grains.

So far as the Nullagine cherts are concerned, sections of specimens of these rocks collected by both H. W. B. Talbot and the present writer, and examined by R. A. Farquharson, have shown no trace of organic structure, and, furthermore, the chert beds appear on the present surface of the ground no matter what horizon it represents, and have not been recognised interbedded below the tops of the ridges. Again, they have been found by Talbot as a thin

sloping coat on the shale outcrops, with which they are unconformable.*

With regard to the second explanation given above, the solubility of quartz in ground waters at the normal temperature and pressure is so minute that this explanation fails utterly to account for the accumulation of several feet, in places as much as 12 feet, or more, or chert capping. On the other hand the silicic acid generated in accordance with equations (8) and (9) from the action of weathering sulphides upon kaolin and mica, would be sufficient to provide the material for the chert beds, and would be generated in a form and under circumstances especially favourable to its transport by capillarity to either the top flat surfaces of the ridges or their exposed sloping outcrops. Erosion would prevent its accumulation in large masses on the latter. In this connection it is to be noted that the attack of the shales by the sulphuric acid solution may take place wholly in the beds where the sulphides are decomposing, or in part at the surface, whither the acid solutions may migrate, and where they will become concentrated by evaporation, and therefore more active.

Whether an original bed of limestone had any part in the formation of the chert is not certain, their thinly bedded structure suggests the replacement of a shale, but many of the cherts when sectioned exhibit minute crystals of calcite, and the frequent occurrence of chert or opal as a pseudomorph after calcite has been noted in every region of the world. At Alunite Gully chert pseudomorphs after calcite concretions are quite abundant. No explanation of this phenomenon appears to have been put forward, but it is probably due to the formation of a solid hydrous calcium silicate by interaction between limestone and silicic acid solutions, and the subsequent decomposition of the silicate by atmospheric carbonic acid. This indicates a reaction of the following type which is reversible under slight variations of conditions—

$$H_2SiO_3 + CaCO_3 = CaSiO_3 \cdot H_2O + CO_2.$$

the silicic acid ultimately becoming fixed at the exposed surface by dehydration in the hot sun and dry air.

VI.—Locality Notes.

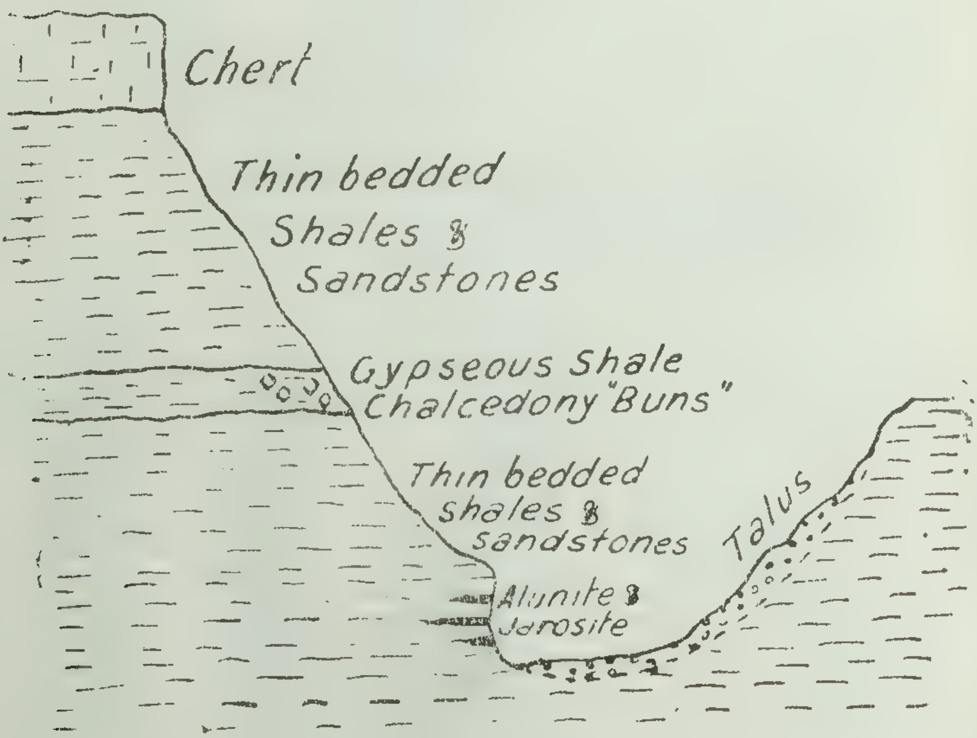
Alunite Gully, Chichester Range, (Roy Hill Station).—Alunite was first found by the writer a few yards upstream from the point where the Roy Hill-Nullagine motor road and telegraph line cross the creek. This is about nine miles south-east of Well 48. Attention was called to the locality by the numerous boulders of manganese ore in the stream bed. The sides of the gully are steep slopes of almost horizontally bedded Nullagine shales and soft sandstones with a prominent chert capping 10ft. thick. The total height

* G.S.W.A. Bull. 83, pp. 42–45, etc.

of the cliffs is from 70 to 100 feet. Most of the pebbles in the stream are chert or flint, but manganese ores are abundant for some distance along the stream below the point where alunite and manganese ore were found *in situ,* on opposite sides of the gully. Limonite pseudomorphs after pyrite-marcasite nodules are not uncommon in the talus and creek bed.

A section through the alunite site is shown in Figure 2. Below the chert cap the whole section consists of thinly bedded shales and soft sandstones. About half way down, a powdery shale carries innumerable crystals of gypsum averaging about 25 mm. (1 inch) in length. In close association are found numerous chalcedony "buns"

Fig. 2.



Section at Alunite Gully, Chichester Range.

or flinty replacements of calcareous concretions, ranging from 3 to 15 cm. in diameter. In the bottom six feet of the section, where the stream has cut a vertical face in soft carbonaceous shales, numerous thin lenses of yellowish-white to ochre-yellow alunite are interbedded with the shales. These lenses are from 2.5 to 5 cm. (1 to 2 in.) in thickness. The mineral in them is granular and porous like the Kanowna alunite, and whilst occasionally very friable, is more often moderately tough. The frequent yellow colour is due to intergrown jarosite, comparatively pure specimens of which are found in associated flat cakes as thick as the alunite lenses, but much less extended and inclined to be mammilated in outline. Fairly pure jarosite also forms borders to some of the alunite lenses. A few yards farther downstream a white fibrous efflorescence was abundant in a sheltered

part of the creek bank. This proved to be epsomite, with traces of salt, but no gypsum or alum. On the opposite side of the narrow gully the shale at the gypsum horizon showed no gypsum but instead was strongly impregnated with hydrated iron and manganese ores, the latter also forming veinlets and flat interbedded cakes with mammilated surface. This was proved to be the source of the boulders of psilomelane and pyrolusite in the creek bed. The paragenesis of the various secondary minerals found here has been dealt with on a previous page.

Analyses have been made of several of the minerals, the results being as follow:—

	Manganese ores, (1.) Amorphous.	Alunite Gully. (2.) Crystallised.
MnO_2	60·66	77·74
MnO	2·43	*Nil*
Fe_2O_3	9·60	11·74
Al_2O_3	much	small
SiO_2	9·24	5·60

(1) Psilomelane and pyrolusite intimately mixed with limonite, kaolin, and probably gibbsite.

(2) Pyrolusite with admixed limonite.

	Alunite and Jarosite, (3.)	Alunite Gully. (4.)	(5.)
SO_3	37·66	36·23	30·42
Al_2O_3	32·87	24·21	7·88
Fe_2O_3	4·01	15·83	34·69
K_2O	10·19	9·48	8·46
Na_2O	·47	·46	·46
H_2O+	13·09	12·54	10·16
H_2O-	·04	·07	·20
P_2O_5	·25	·14	·06
TiO_2	·31	·25	·47
SiO_2	1·30	1·09	7·27
Carbon	·05	*Nil*	·14
NaCl	trace	·13	*Nil*
	100·24	100·43	100·21
Equal to			
Jarosite	8·4	32·9	72·4
Alunite	89·4	65·6	18·8
Quartz	1·3	1·1	7·3

(3) Almost pure white, friable, porous alunite from 2.5 cm. vein. Under microscope it is all perfectly crystallised in pseudo-cubes 3 to 7 microns in diameter. Faces present $r^1r^2r^3r_1r_2r_3$.

(4) Naples yellow (Ridgway 19^1e), tough, porous alunite from 4 cm. vein. Fairly well crystallised in pseudo-cubes of 3 to 5 microns.

(5) Jarosite cake with banded colouring, mustard yellow (19^1b) to citrine drab ($21^{111}i$), due to irregular distribution of alunite and carbonaceous matter. Porous and microgranular.

Chert, Alunite Gully.

(6).	SiO_2	Al_2O_3	Fe_2O_3	$CaCO_3$	H_2O+	Total
	97·60	*Nil*	1·95	0·21	0·25	100·01

(7) Banded brown chert from summit of ridge.

Conical Hill, Lofty Range. Five miles north-east of Conical Hill at the western end of Lofty Range, H. W. B. Talbot found the Nullagine shales to enclose numerous concretions of calcite. These were oblate spheroids or ellipsoids, and represent the type of concretion which gave rise to the chalcedony "lens" of Alunite Gully. An analysis was made of one of the Lofty Range concretions, measuring 7.5 x 5.5 x 2.5 cm.

Calcite Concretion near Conical Hill.

Insoluble in dilute HCl	... ...	25·14
Soluble	Al_2O_3	1·62
	Fe_2O_3	3·66
	CaO	37·72
	MgO	1·26
	CO_2	29·61
	H_2O and organic	1·35
		100·36

This is a mixture of about two-thirds calcite, one-third kaolin, quartz and limonite, the last being evenly distributed through the concretion and representing prior ferrous carbonate.

Millstream Station. In the vicinity of Millstream homestead, and at various points to the south and west of it, L. A. Le Souef has collected a number of specimens indicating similar conditions to those which prevail at Alunite Gully. Grey and black shales of the Nullagine series, which are almost horizontally bedded, carry marcasite-pyrite nodules with limonite pseudomorphs after them. The pseudomorphs are spherical or lenticular in form, with diameters ranging from 2 to 7 cm. Usually they consist of fairly pure limomite, but at other times of an intimate mixture of chalcedony and limonite. Their surfaces are finely to coarsely crystallised, showing mostly cube faces, though one specimen had octahedron faces only, and others showed both forms. A typical specimen contained:—

Fe_2O_3	Mn_2O_3	Al_2O_3	SiO_2	H_2O+	H_2O-	Total
86·61	0·22	1·69	2·07	9·02	0·18	99·79

Chert is also found, and one specimen is composed of thin bedded shale, partly altered to chert, the boundaries between the silicified and unsilicified portions being sharply defined, but very irregular.

Jarosite is fairly abundant. Two miles east of Gregory's Gorge it forms a vein 2 to 2.5 cm. wide, cutting across the flat shales at an angle of 60°. The colour is close to mustard yellow (between Ridg-

ways 19[1]b and 19[1]d). It is highly porous, but tough, and made up of microscopic granules. Only a very few of the grains are recognisable as crystals under the microscope, these being transparent hexagonal plates with dark centres. Its composition is:—

SO_3	Fe_2O_3	Al_2O_3	K_2O	Na_2O	H_2O-	H_2O+	P_2O_5	TiO_2	SiO_2	C
32·96	35·14	9·11	9·78	*Nil*	0·16	11·84	0·57	0·14	0·82	*Nil*

Total ... ... 100·52

This represents a mixture of

Jarosite.	Alunite.	Quartz, etc.
73·5	24·6	2·0

The calculated density of this mixture is 3.06. The actual density of the mass was found to be 3.02, pure jarosite being 3.20.

In Gregory's Gorge, about 15 miles west of the homestead, a similar vein-filling of jarosite was found to carry the following constituents soluble in HCl—

K_2O	Na_2O	NaCl
7·87	1·32	0·29 per cent.

About 15 miles south of the homestead there is an almost vertical and persistent vein of impure alunite 8 to 10 cm. wide. This is white or yellow in colour with bright red and brown iron stains. It has a columnar to almost fibrous structure across the vein. It is tough but highly porous, and under the microscope is seen to be granular and imperfectly crystallised, the pseudo-cubical crystals being 2 to 5 microns in diameter. Some of the whiter material was found to contain—

K_2O	Na_2O	SO_3
7·77	0·36	26·42

This is equal to about 70 per cent. alunite, the balance being mainly siliceous matter. The yellower portions of the vein contain a little jarosite in intimate admixture.

Tambrey Station.—Between Tambrey homestead and Middle Creek police station, limonite pseudomorphs after marcasite-pyrite nodules precisely similar to those found at Millstream are abundant under like geological and physiographical conditions. This locality is worthy of a careful search for alunite and other secondary sulphates.

Nullagine.—On the slopes around Watty's Flat, which is the centre of gold mining activity, efflorescences of water-soluble salts are common in dry weather. A very abundant powdery white efflorescence was found on the slopes on the east side of the flat, covering to a depth of several centimetres an outcrop of a bedded white kaolin (kaolinised lava?) of the Nullagine Series. This efflorescence was found to consist of—

Kaolin.	Gypsum.	Epsomite.	Na_2SO_4	NaCl	Total.
71·3	17·2	10·6	0·5	1·4	100·0

A similar looking efflorescence was found just under the hard grit capping of a knoll of Nullagine sediments to the south-west of the last described specimen. This was found to be mainly epsomite, with a little salt, and some kaolin and fine quartz sand.

At the head of Grant's Gully, on the west side of Watty's Flat, a tunnel and winze have been put in to follow a prominent auriferous zone of the Nullagine conglomerate. In the winze the conglomerate is highly pyritous, the sulphide occurring in scattered crystals and granular aggregates as well as in well water-worn pseudomorphs after some highly ferruginous silicate rock (see analysis below). On the walls of the tunnel above the sulphide zone, a pure white efflorescence was collected which consisted chiefly of granular, highly birefringent epsomite, with traces of gypsum, and a little alum (pickeringite ?), the solution containing aluminium sulphate.

Tracing the outcrop of this slightly-dipping auriferous zone round the brow of Bingham's Hill where it has been mined to a short distance at very many points, the gold-bearing rock was found to be characterised throughout by an unusual amount of limonite at the outcrop. A few feet in from the surface the limonite was frequently found to give place to jarosite, the bright yellow mineral forming an excellent guide to the width and direction of the auriferous impregnation.

Typical specimens of sulphide and oxidised conglomerate (G. S. M. *1/1387, 1/1483) were found to have the following composition:—

Auriferous Conglomerate, Nullagine.

	SiO_2	Al_2O_3	Fe_2O_3	FeO	MnO	MgO	CaO	Na_2O
Sulphide	54·56	4·74	0·89	0·17	*Nil*	0·38	0·32	0·52
Oxidised	60·65	5·79	20·22	2·07	*Nil*	0·44	*Nil*	·64*a*

K_2O	H_2O—	H_2O+	TiO_2	CO_2	P_2O_5	SO_3	FeS_2	Cl	As	Ni
1·32	0·20	1·87	0·19	*Nil*	0·18	*Nil*	34·57*	trace	·06	·02
1·70*a*	·77	4·13	·11	*Nil*	0·04	3·49	*Nil*	·02	trace	*Nil*

Pb, Cu, Bi, Co, Zn, Sb.	Total	Gold *b*	Silver *b*
Nil	100·01	0·500	0·350
Nil	100·07	1·144	0·162

a Sol. in HCl ; Na_2O, 0·18 ; K_2O, 1·02. *b*. Ounces per ton.

* Fe, 16·09 ; S, 18·48.

The oxidised ore is calculated to contain 10.95 per cent. of jarosite of the following composition:—

Jarosite, Nullagine.

SO_3	Fe_2O_3	K_2O	Na_2O	H_2O	Total
32·2	48·1	7·5	1·3	10·9	100·0

* Register numbers in the Geological Survey collection.

On examination of this and numerous other specimens of a similar nature for jarosite, it was found that many oval or cubical cavities originally known to be occupied by pyrite, were wholly or partly filled with a bright yellow mineral sometimes in soft powder, sometimes in fine dense masses. This mineral gave all the chemical reactions for jarosite, and under the microscope was found to be composed of transparent amber-yellow crystals of the hexagonal system, the faces being $r^1r^2r^3r_1r_2r_3c^1c_1$. The diameter of the crystals varied from 0.005 to 0.100 mm. In addition to the cavity fillings, quite a considerable amount of jarosite was found to be present as strings and masses of small rounded granules, impregnating the kaolinised rock pebbles, and chalcedonic binding material of the conglomerate. (*Vide* G.S.M. 1509, 3167, 1/1483.)

Glen Ross (Upper Ashburton River).—In a carbonaceous shale in this locality pickeringite forms a network of veins averaging one centimetre in width. It is colourless and substranslucent, with a compact sub-fibrous structure. An analysis shows:—

Pickeringite. Glen Ross.

Al_2O_3	MgO	MnO	FeO	K_2O	Na_2O	SO_3	H_2O	Total
12·01	4·15	0·60	trace	0·08	*Nil*	37·28	45·93	100·05

The density of the mineral is 1.87; hardness 2.5; mean refractive index, 1.45. It is readily soluble in water, and effloresces on exposure to dry air. The analysis shows it to be typical pickeringite,

$$MgSO_4\ Al_2\,(SO_4)_3\cdot 22H_2O.$$

Upper Gascoyne River.—A greyish white efflorescence collected somewhere on the Upper Gascoyne in 1921 was found to be a mixture of 35 per cent. clay and sand with 65 per cent. soluble sulphates. An analysis of the latter showed—

SO_3	Al_2O_3	CaO	MgO	Na_2O	K_2O	Cl	H_2O	Total	Less O = Cl
45·37	12·57	·55	1·81	10·43	·03	1·39	28·16	100·31	0·31

Recrystallisation gave many monoclinic crystals with much fine granular matter.

There is little doubt that the chief constituents of this efflorescence are tamarugite ($Na_2O.Al_2O_3.4SO_3.12H_2O$) and pickeringite (magnesia alum), but as no definite information regarding its occurrence is obtainable, there is some doubt whether it was derived from Nullagine sediments.

VII.—Summary.

This paper describes the occurrence and genesis of chert and of several secondary sulphates in the Nullagine series of the North-Western Division of Western Australia.

I. The introduction gives a brief résumé of the present state of knowledge of the Nullagine beds, whose age is tentatively given as Keweenawan.

II. The sulphates recorded are gypsum, epsomite, tamarugite, pickeringite, copiapite, alunite, and jarosite. These are found either as vein fillings, efflorescences or embedded crystals in soft sediments.

III. Chert is shown to be widespread over the Nullagine region as hill cappings or coatings to hill slopes, and as thickly strewn "gibbers" on broad plains.

IV. In tracing the origin of the sulphates differences are indicated between the ground waters of the Dry Lake Region and of the Nullagine region, typical new analyses being given of both. The prevalence in the Nullagine series of pyrite-marcasite concretions and goethite pseudomorphs after them is emphasised.

V. The paragenesis of the sulphates and chert, and of some associated minerals, is detailed, and their origin traced to the weathering of the pyrite and marcasite.

VI. Descriptions of individual occurrences are given, including new analyses of the sulphates, chert, and associated minerals from this region.

AN AUSTRALIAN CRETACEOUS CIRRIPEDE.

By Thomas H. Withers, F.G.S., F.Z.S.

(Published by permission of the Trustees of the British Museum.)
Communicated by L. Glauert, 13th March, 1923.

Mr. L. Glauert, of the Western Australian Museum, Perth, has kindly submitted to me some Cirripede remains that he has obtained from the Gingin "Chalk," with a request for a report on them.

The fossils from this deposit have been described by R. Etheridge, jnr. (1913, Bull. No. 55, W. Austr. Geol. Surv., iv., Palaeont. Contrib. to the Geology of Western Australia), who considered them to be of Upper Cretaceous age, and he gives in his paper full references to previous work on the Gingin "Chalk" and its fossils.

So far only a single Cirripede valve is known from the Australian Cretaceous, and this is the valve, a tergum from the Gingin "Chalk," described by R. Etheridge, jnr. (1913, pl. iii., figs. 4, 5), as a scutum, under the name *Pollicipes* (?) *ginginensis*.

Mr. Glauert's material comprises four valves, two carinæ and two terga. Although these valves evidently belong to the same species, and may all be referred to *Pollicipes* (?) *ginginensis*, the terga are more complete than the fragmentary holotype, and the carina is now made known. The new material, moreover, enables one to gain a clearer idea as to the affinities of the species.

Calantica (Scillaelepas) ginginensis

(R. Etheridge, jnr.)

(Pl. I., Figs. 1—8.)

1913.—*Pollicipes* (?) *ginginensis*—R. Etheridge, jnr., Bull. No. 55, W.A. Geol. Surv., p. 13, pl. iii., figs. 4. 5.

Diagnosis. A *Scillaelepas* with the valves comparatively thin. Carina, like that of *S. dorsata,* but much thinner, and on the inner surface the apical part is only slightly filled up solid. Tergum elongate, apical part curled towards the scutal side, occludent margin concave, and the scutal angle broadly rounded and protuberant. Scutum unknown.

Holotype. The apical half of a right tergum (Etheridge's pl. iii., figs. 4, 5) in the West. Austr. Geol. Surv. Colln.

Material.—In addition to the holotype we now have two carinæ and two terga (one right and one left valve).

This species was founded on the apical half of a tergum, but Etheridge described the valve as a scutum, and in consequence of this the original description leaves much to be desired.

Description.—Carina not divided off into parietes and intraparietes, moderately bowed inwards, flatly arched transversely, not carinate, with the basal margin somewhat angularly rounded. Valve comparatively thin, and on the inner surface only a small part below the apex appears to have been thickened and projected freely. The growth-lines are not at all raised, but there are slight traces of weak longitudinal ridges.

Tergum comparatively thin, sub-rhomboidal, elongate, comparatively flat transversely, with the apical part slightly curled towards the scutal side. Carinal margin almost regularly convex, not very distinctly separated into an upper and lower carinal margin; occludent margin concave and inwardly rounded, more than half the length of the scutal margin; scutal margin concave in the middle, the scutal angle being broadly rounded and protuberant. A flat-topped ridge with fairly steep sides extends from the apex and widens considerably towards the base, and this ridge is followed on the scutal side by a wide depression bounded by the rounded occludent margin; the flat-topped ridge is variably developed in the two terga. On the outer surface the growth-lines are irregularly raised, and the valve is weakly and finely ridged longitudinally, but the longitudinal ridges are more clearly seen on the scutal side and on the flat-topped ridge. On the inner surface only a very narrow border along the inner occludent and upper carinal edges is raised and thickened and marked with growth-lines.

Measurements.—Carina; the smaller valve has a length of 3.2mm., and the larger slightly incomplete valve, a length of 8.8mm. Tergum; the right valve has a length of 11.0 mm., and a breadth of 6.0mm., and the left slightly incomplete valve a length of 8.2mm. and a breath of 4.8mm. The holotype tergum is said to have a breadth of 9.0mm.

Systematic Position.

The discovery of new types of fossil Cirripedia, while adding to our knowledge of the evolution of the group, is making it increasingly difficult to refer isolated valves to their proper systematic position. Nevertheless, when one studies the known forms seemingly quite minor characters serve to distinguish the valves of the different genera.

The chief features of the present valves are (1) the carina is simple, that is, it is not divided off into parietes and intraparietes, nor is it carinate, (2) the tergum has a rather wide, flat-topped apicobasal ridge on the scutal side.

Etheridge was doubtful whether he should refer the holotype (tergum) of the present species to the genus *Pollicipes* or *Scalpellum*, but he left it in *Pollicipes* with a query. He suggested a comparison with *Pollicipes striatus* Darwin, and *Scalpellum maximum* (J. De C. Sowerby), but both those species are now included in the genus *Scalpellum* (*sensu lato*), the former being included in the sub-genus *Cretiscalpellum* Withers, and the latter in the sub-genus *Arcoscalpellum* Hoek.

Our species is obviously not an *Arcoscalpellid,* for in that group the carina is divided off into parietes and intraparietes. It cannot be referred to *Crestiscalpellum,* in which the carina, while simple, is carinate, and the tergum has usually a wide furrow extending from the apex to the scutal margin, and bounded by a sharp fold close and parallel to the occludent margin.

Much more resemblance is shown to the valves in the sub-genus *Scillaelepas* of the genus *Calantica,* especially such a form as *C.* (*Scillaelepas*) *dorsata* (Steenstrup), from the Danian of Faxe, Denmark, for the carina agrees in being simple and not carinate, and the tergum agrees in having a flat-topped apico-basal ridge.

Our species differs from *S. dorsata* in the valves being thinner, the carina being filled up solid only to a small extent below the apex, and in the tergum by the apical part being curled towards the scutal side, the occludent margin being concave, and the scutal angle being broadly rounded and protuberant.

Having only a carina and tergum, it may be rash to give the reconstruction of the capitulum (pl. I., fig. 8), but it will perhaps give added zest to the search for the valves of the lower whorl, from which it would be possible to conclusively show that the present species really is a true *Scillaelepas.*

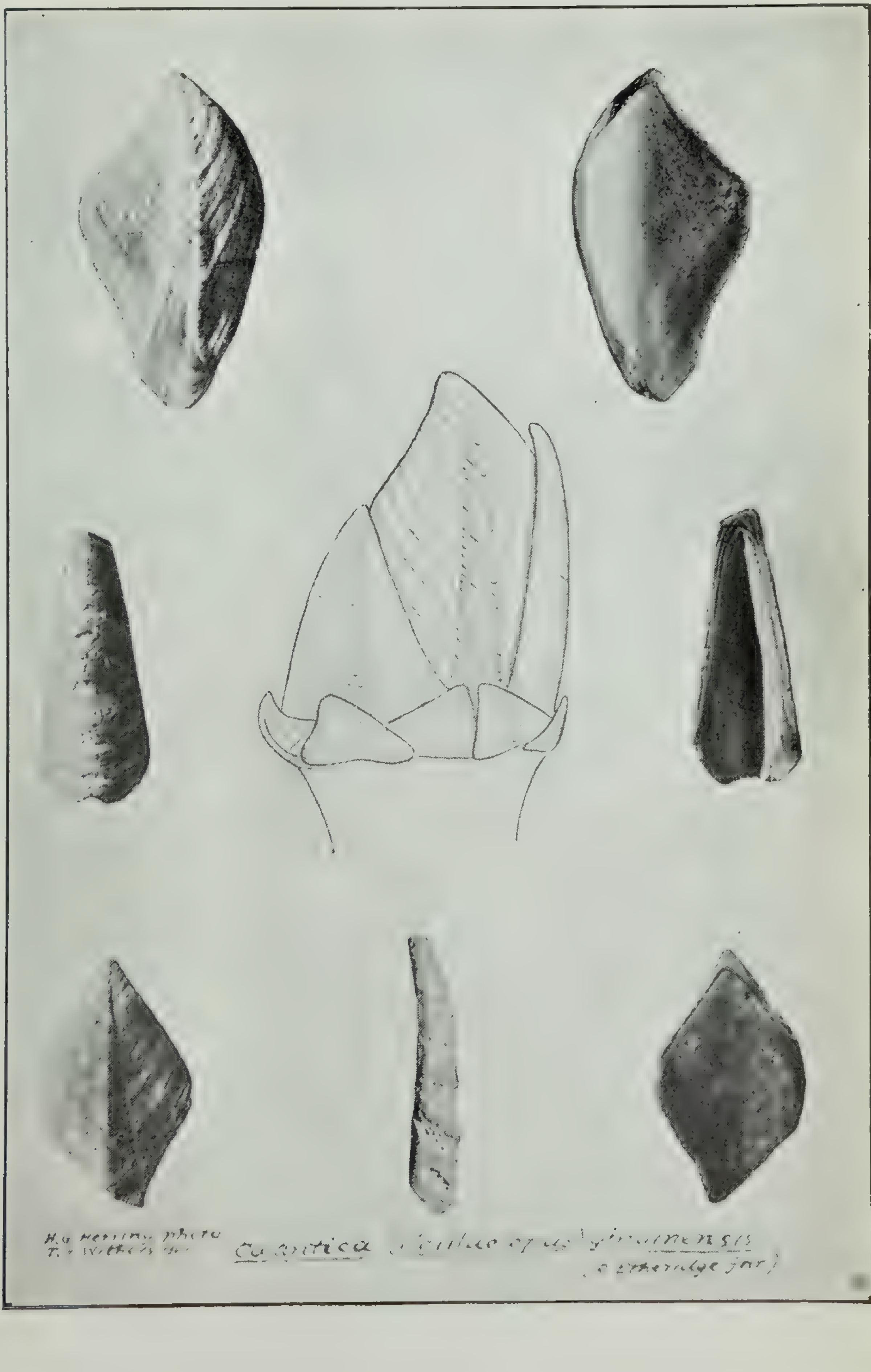
EXPLANATION OF PLATE I.

Calantica (*Scillaelepas*) *ginginensis* (R. Etheridge, jnr.)

Upper Cretaceous (?Upper Senonian): Gingin, Western Australia.

1. Carina.—Outer view, the surface being much worn. W. Austra. Mus., G. 3749.
2. Id.—Inner view.
3. Id.—Side view.
4. Tergum (right).—Outer view. W. Austr. Mus., G. 3750.
5. Id.—Inner view.
6. Tergum (left).—Outer view. Brit. Mus., In. 22434.
7. Id.—Inner view.
8. Reconstruction of capitulum. The carina and tergum only are so far known.

1 — 7 × 4 diam.



ON THE ENERGY INVOLVED IN THE RECENT OUTBURST OF BETA CETI.

By Professor A. D. Ross, M.A., D.Sc., F.R.S.E., and R. D. Thompson, M.A., M.Sc., F.R.A.S.

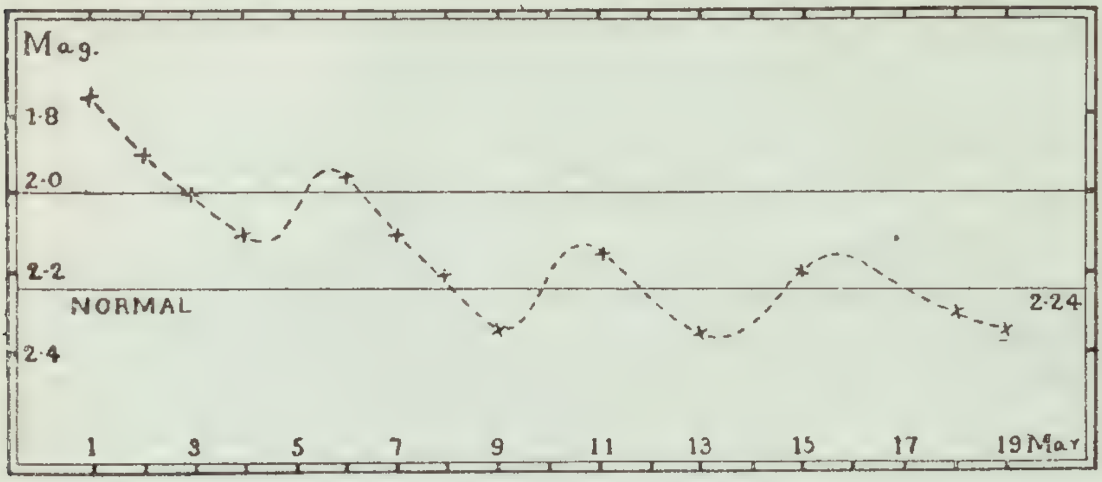
Read 10th April, 1923. The parts shown in brackets, thus [ ] were added in May, 1923.

A cablegram published in the *West Australian* of 1923, February 28, announced that a star of the second magnitude in the constellation of Cetus had become brighter than Aldebaran (1·1 magnitude). According to a further cablegram published the following day the star in question was Beta Ceti (normal magnitude 2·24) and it was said to have increased 17-fold in brightness, that is to —0·7 magnitude. [It now transpires that only three estimates were obtained in Europe of the brightening of the star. The discovery was made by Mr. William N. Abbott at Athens on 1923, Feb. 13. The star was "superior in magnitude to Alpha Tauri (Aldebaran)" and "in the immediate vicinity no other object, except the planet Mars, was comparable in magnitude."* On Feb. 16 Mr. Abbott found Beta Ceti "to have greatly decreased since the night of the 13th. Its magnitude was inferior to Aldebaran (1.1), which it had surpassed on the 13th February, but superior to Gamma Cassiopeiae of 2·24 magnitude."* Mr. Abbott telegraphed his discovery on February 14 to M. Flammarion at Paris, who asked his assistant M. Quénisset at Juvisy to verify the observation. On February 23 M. Quénisset found Beta Ceti as at least of the first magnitude.†]

The authors made a series of careful visual estimates of the brightness of the star on every clear evening from March 1 until by the third week of the month the star came too close to the sun to permit useful observation. The observations were made independently, one set being obtained generally from South Perth and the other from West Perth, although occasional observations had to be conducted from Cottesloe, when haze or smoke would otherwise have vitiated the estimates. Allowance for atmospheric absorption was tested by observations of Alpha Phœnicis—a star of similar spectral type (viz. Ko). As a rule about ten comparison stars were used on each occasion, covering a range of about 0·6 or 0·7 magnitude. The average difference between the two individual determinations on each night was under 0·1 magnitude, and exceeded 0·2 magnitude on only one night (March 13, determinations 2·2 and 2·5).

* Observatory, 1923, April. † L'Astronomie, 1923, March.

The following are the means of the determinations:—Mar. 1, 1·75; Mar. 2, 1·9; Mar. 3, 2·0; Mar. 4, 2·1; Mar. 6, 1·95; Mar. 7, 2·1; Mar. 8, 2·2; Mar. 9, 2·35; Mar. 11, 2·15; Mar. 13, 2·35; Mar. 15, 2·2; Mar. 18, 2·3; Mar. 19, 2·35; [May 3, 2·25]. These values are plotted in the accompanying diagram. It will be



Variation in brightness of Beta Ceti.

observed that the light intensity in March was settling down to its normal value of 2·24 in a series of minor fluctuations having a five day period with maxima about March 6, 11, 16, and minima about March 4, 9, 14. [It is interesting to note that carrying back this oscillation we would have maxima in Europe about February 14 (or 13), and 24 (or 23), and a minimum about February 17 (or 16). It is possible that this explains the relative brightnesses found by Mr. Abbott and M. Quénisset.]

Remembering that an increase of one magnitude in the brightness of a star means an increase of 151 per cent. in the light, it appears that in its outburst Beta Ceti has radiated an extra amount of light equivalent to at least 20 days' normal output. The star's spectroscopic parallax is 0·042″,* corresponding to a distance of about 78 light years. Hence, as the sun's stellar magnitude is —26·6, and it is equivalent to 1,575 $\times$ 10^{24} candles in total brightness, we get Beta Ceti at normal as equal to 115 $\times$ 10^{27} candles. Now Rayleigh has found that the luminous radiation from a standard candle equals 2·2 foot-pounds per minute.† Hence the normal light of Beta Ceti represents an output of 37 $\times$ 10^{31} ft.-lbs. per minute. Therefore the extra luminous energy radiated in the outburst must have been about 74 $\times$ 10^{32} ft.-lbs. This is only part of the total energy radiated. In radiation from a body at a temperature of about 8,000° C. the luminous energy amounts to just over 40 per cent. of the total radiant energy. For higher or lower temperatures the luminous energy is a smaller proportion, being only 20 per cent. at about 3,500° or 14,000° C. We shall

* Contributions from Mt. Wilson Observatory.

† Rayleigh; Collected Papers. Angstrom's value is about double Rayleigh's.

not be far out if we assume 30 per cent. in the case of Beta Ceti, thereby finding that the extra output of energy was about 24×10^{33} ft.-lbs. in all, or at the average rate of 25 billion billion horse-power over a three-week period.

It has been suggested that such an outburst might be due to the collision of the star with another celestial body. Beta Ceti is a giant star* with a mass say 50 per cent. greater than the sun's mass, and a radius say 40 times the sun's radius. A body drawn to it from an indefinitely great distance would therefore fall into it at a speed of about 74 miles per second.† The mass of this body, in order to provide the necessary kinetic energy for the subsequent radiation, would require to be about 45×10^{20} tons. The Earth's mass is about 59×10^{20} tons, while Jupiter is over 300 times larger and the planetoid Ceres about 6,000 times smaller. If then the outburst has been caused by the impact of another celestial body, that body has been of planetary size. Stellar masses would have given an effect of order a million times greater and cometary masses an effect of order a million times smaller.

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* Contributions from Mt. Wilson Observatory.

† The parabolic velocity, or velocity from infinity, is 380 miles per second for the sun. Moulton, Celestial Mechanics.

THE PRESENT POSITION OF FOREIGN EXCHANGE.

[ABSTRACT.]

By Professor E. O. G. Shann, B.A.

Read 10th April, 1923.

To have prices stable both in space and in time has been the ideal implicit in all monetary development.

The pre-war system, centred upon London as the free market for gold where any credit might be drawn in gold, provided very effectively for stability in space and somewhat less effectively for stability in time. Its merits in the former respect had in the nineties been given a wider extension by the elaboration of the gold exchange system, steadying the rate of exchange between gold-using and silver- or paper-using countries. Improvement in point of stability in time was practicable by the organisation of the banks in each région around a central reserve bank, controlling the price of credit.

Incidentally the gold exchange system demonstrated that the internal circulation of gold was not essential to the adjustment of the purchasing power of a currency in stable relation with gold.

The pre-war system attained such adjustment of all currencies without any governmental or international machinery. Normal seasonal fluctuations were masked without risk by bankers' loans, abnormal strains offset by transfers of the international cash, gold bullion.

The fluctuations of purchasing power and of exchange rates consequent upon the abandonment of gold-convertibility and the cessation of adjustment in cash, have ruined the small investors of Europe and impose an onerous risk of fluctuating prices on all international trade. Stability both in time and in space has thus been lost. Even in gold-faithful countries, such as U.S.A. and Sweden, fluctuations in gold prices have been such as to undermine belief in the merits of gold-convertibility. American bankers have now an opportunity to repeat the work done in the 19th century by London, in finding the gold for a maximum area of markets using sound money.

Proposals for reconstruction take two main directions, one aiming at a renewal of the old stability in space, others at an improved stability in time. It is generally agreed that the exchanges can only be stabilised if the depreciated currencies of Europe are devalued and fresh mint-pars well within their resources are established as between them and the dollar. Deflation, the only sound alternative, would render the war-debt-service an intolerable burden, and, in any case, would mean prolonged depression and unemployment. The new mint-ratios would be administered on the gold-exchange plan of cashing notes into gold or foreign money only for the purpose

of settling external indebtedness. There should at present be no restoration of gold to circulation in Europe. Economy of gold by this means might, however, produce a fresh depreciation of a degree similar to that of 1896-1914. To prevent any such fluctuations Irving Fisher, of Yale, has won considerable support for a scheme to stabilise purchasing power by making the gold value of the monetary unit rise or fall with an index-number of general prices, thereby automatically cancelling price-movements.

The proposal might achieve stability in time at the cost of upsetting that convertibility of all monies, termed stability in space, which is the great merit of the gold exchange system. In default of international action, this objection is fundamental. The aim of stability of value from year to year might be less rigid, but for that reason more safely realised by effective control of credit supplies through the central banks. This would call for no legislative tinkering with money. The machinery for its operation is already in existence.

AUSTRALIAN FORMICIDAE.

(With ten text figures.)

By J. Clark.

Read 8th May, 1923.

The classification of the Australian Ants belonging to the subfamily *Cerapachyinae*[1] has long been a matter of much doubt amongst Myrmecologists, mainly, it would appear, through the lack of sufficient material and knowledge of their habits and life histories.

Prof. Wheeler in a valuable paper on "The Australian Ants of the ponerine tribe *Ceraphachyini*,"[2] dealt with all the Australian species, and added nine, bringing the total up to 28 species and varieties. Since then Crawley[3] has added one, and in the present paper it is proposed adding 10 more, bringing the total to 39, of which 16 are Western Australia forms. (*Eusphinctus* (*Nothosphinctus*) *clarus*, Forel, was recorded from Adelaide River, N.W. Australia, but as this river is in the Northern Territory the species is excluded as a Western Australian form.)

In his paper, Wheeler (p. 217) quotes and supports Ernest Andre,[4] who says:—"I believe rather, till proof to the contrary is forthcoming, that the species of the genus *Sphinctomyrmex* should be restricted to the single *S. stali,* of Brazil, which is the type, and that all the Asiatic and Australian species should constitute the genus *Eusphinctus,* Emery, without distinctions between those having 12 or 11 antennal joints. Besides such characters as may be exhibited by the still unknown worker of *Sphinctomyrmex,* this genus is characterised by a normal female, whereas the female of *Eusphinctus* is ergatomorphic."

Lately several colonies of this group of ants have been found around Perth, the study of which has yielded additional very interesting facts to the existing knowledge of the group. This information tends to complicate matters a little at present, as one species of the genus *Eusphinctus*, s. str. (*E. occidentalis,* sp. nov.) has a perfectly developed female. The nest of this species contained 20 normal but dealated females.

It will be necessary to alter the existing classification, but with the present state of our knowledge it is better to let matters stand

(1) Psyche, vol. xxvii., pp 46-55, 1920.
(2) Proc. Amer. Acad. Arts and Sc. 53, 3, pp. 215-265, 1918.
(3) Ann. Mag. Nat. Hist. 9, pp. 433-4, 1922.
(4) Rev. d'Ent. 24, p. 205, 1905.

as at present pending further investigation, as during the short time devoted to the group the following facts have been discovered:—

(a) That the pupæ of *Eusphinctus* and *Phyracaces* are enclosed in cocoons similar to those of the typical *Ponerinae.*

(b) A fully developed and winged female has been found in the genus *Eusphinctus,* s. str., which was characterised as having an ergatoid female.

(c) The genus *Phyracaces,* in addition to having winged females, and developed females without wings, also includes ergatoid females, of which *Ph. heros,* Wheeler, appears to be a good example.

The female of *Ph. punctatissima,* sp. nov., is fully developed but has no traces of wing stumps.

The female of *Ph. gilesi,* sp. nov., is ergatoid, differing from the worker only by larger size, and in possessing ocelli.

The female *Ph. constricta,* sp. nov., is ergatoid, and was found, solitary, under a log, apparently founding a new colony.

The female taken with *Ph. simmonsae,* sp. nov., is ergatoid; this specimen was found with the brood, in the bottom chamber.

No females of *Ph. ruficornis,* sp. nov., were obtained in the nests, but two winged male pupæ were found in their cocoons. For the present the females of this group can only be regarded as of three forms—fully developed and winged; thorax developed but not winged; ergatoid.

From the above it will be seen that our knowledge of the females of the genus *Phyracaces* is not only incomplete, but is unsatisfactory, and careful investigation must be made before a satisfactory conclusion can be arrived at.

The females of *Eusphinctus* (*Nothosphinctus*) *fulvidus,* sp. nov., are ergatoid, closely resembling *E.* (*N.*) *manni,* Wheeler, and *E.* (*N.*) *imbecillis,* Forel.

The females of *Eusphinctus* (*Eusphinctus*) *steinheili,* Forel, and of *Eusphinctus* (*E.*) *hackeri,* Wheeler, are ergatoid; the female of *Eusphinctus* (*E.*) *occidentalis,* sp. nov., is winged.

Nests of *Eusphinctus, Nothosphinctus,* and some species of *Phyracaces* have been found associated with nests of the genus *Myrmecia.*

Ph. simmonsae, sp. nov., forage as a colony; *Ph. punctatissima* sp. nov. forage (or scout?) singly, running rapidly over and under stones, logs, leaves etc., with the abdomen turned up, in many cases almost touching the back of the thorax.

Types of the new species are in the author's collection.

Eusphinctus (Eusphinctus) occidentalis, sp. nov. (Fig. 1).

Worker: Length 2.8—3.5mm.

Yellowish brown, mandibles and incisures of the antennal joints reddish; hairs yellow, moderately long, appressed, longest on the gaster; antennae and legs clothed with short yellow pubescence.

Head slightly longer than broad, slightly broader in front than behind, occipital border concave, corners sharp; frontal carinae approximated, surrounding the antennal insertions in front, truncated behind, extending to the top of the depression connecting the antennal fovea; clypeus short and rounded. Eyes and ocelli absent. Mandibles small, sharply bent near their base, distinctly dentate. Antennae short and stout, scapes about half the length of the head, gradually thickened to their apex; first funicular joint slightly longer than broad, second to ninth broader than long, apical joint pointed, longer than the four preceding

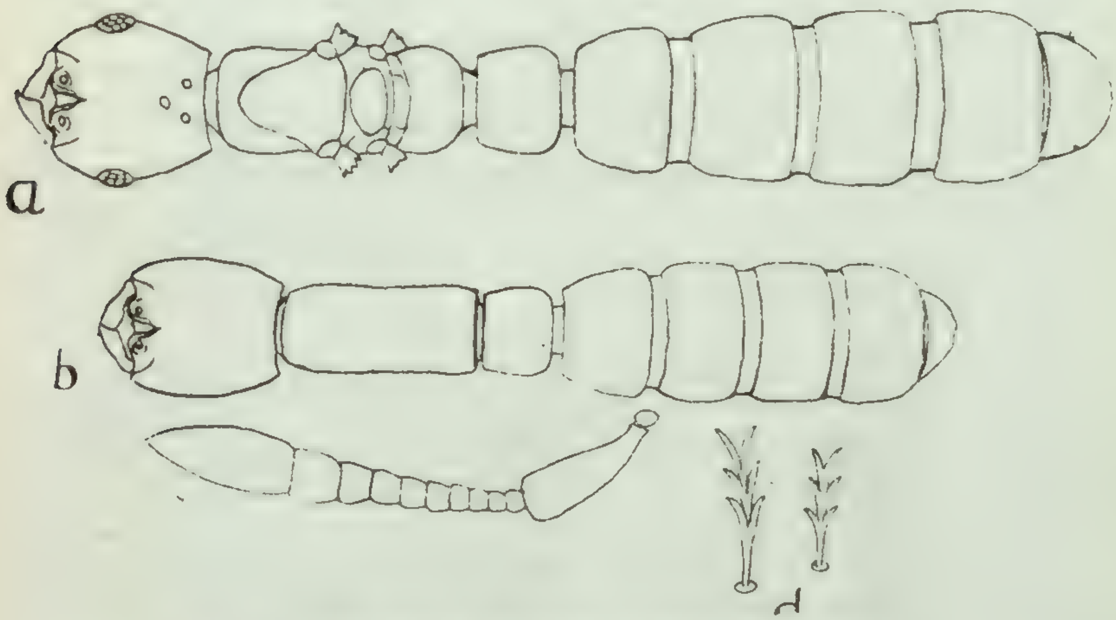


Fig. 1. ***Eusphinctus (Eusphinctus) occidentalis*** sp. nov.
a. Dorsal view of female. *b*. Dorsal view of worker. *c*. Antenna of worker. *d*. Type of hairs on larva.

joints together. Thorax fully twice as long as broad, pronotum slightly broader than the epinotum, mesoepinotal suture feebly indicated, pronotum rounded and marginate in front, epinotal declivity marginate on the sides and top, corners sharp. Petiole broader than long, broader behind than in front, anterior border marginate, corners sharp, posterior corners well rounded; dorsal surface convex; ventral surface with a sharp hooked tooth in front. Postpetiole broader than long, distinctly broader behind than in front, sides and anterior border nearly straight, ventral surface in front protuberant and rounded. First gastric segment twice as broad as long. Pygidium truncate, flattened, submarginate and minutely spinulose on the sides and tip.

Female: Length 3.7—4.3mm. (deälated).

Differs from the worker in the following particulars:—Head, thorax, and petiole dark reddish brown, gaster yellowish brown, antennae and legs dark yellow; hairs long and yellow, more numerous on the gaster than elsewhere. Punctures finer and not so dense. Head as broad in front as behind. Eyes and ocelli moderately large and convex, the eyes placed well in front of the middle of the sides. Thorax two and a quarter times longer than broad, with distinct pronotal, mesonotal, scutellar, metanotal, parapteral, sternal and mesepimeral sclerites; wing stumps present and conspicuous. Gaster two and a half times longer than broad. Pygidium truncated, entire, convex, very minutely spinulose on the sides and tip.

Pupae, enclosed in cocoons.

Hab.: Western Australia, Mundaring (J. Clark).

Described from a colony consisting of 360 workers, 20 females, and a large number of eggs, larvae and pupae. The nest, which was under a small stone, was of very simple construction, consisting of a few small compartments connected by several passages and all were on the surface immediately under the stone. The eggs, larvae and pupae were in the compartment farthest from the entrance to the nest. A colony of *Myrmecia vindex* Sm. was under a large stone adjoining the one covering the nest of *E. occidentalis*.

EUSPHINCTUS (NOTHOSPHINCTUS) FULVIDUS sp. nov. (Fig. 2).

Worker: Length 3.4—5mm.

Brownish yellow, ranging to yellow in some specimens, mandibles, frontal carinae, and incisures of antennal joints darker; hairs on the head, thorax and gaster yellow; antennae and legs with short greyish pubescence. Head distinctly longer than broad, as broad in front as behind, finely and densely punctate, occipital border concave, with blunt posterior corners; frontal carinae short, surrounding the antennal insertions in front; carinae of the cheeks distinct; occipital border marginate; clypeus short and rounded. Eyes and ocelli absent. Mandibles curved at their base, external border slightly concave, strongly and evenly dentate. Antennae robust, scapes not half the length of the head, gradually thickened to their apex; funicular joints one to ten broader than long, the terminal joint slender, and longer than the four preceding joints together. Thorax twice as long as broad, finely and sparsely punctate, flattened above, sub-marginate on the sides, epinotal declivity steep and straight, with its sides and upper border marginate, mesonotal suture feebly indicated. Petiole broader than long, broader behind than in front; in profile as long as high,

ventral surface in front with a large blunt tooth. Postpetiole, one and one-half times broader than long, broader behind than in front, the anterior border straight, lateral borders slightly convex, corners bluntly rounded. Gastric segments broader than long, separated by pronounced constrictions. Pygidium truncated, blunt and entire at the tip, submarginate and minutely spinulose on the sides and tip.

Female: Length 7.6mm.

Differs from the worker in the following particulars:—Brownish yellow, mandibles and incisures of the antennal joints darker; hairs more abundant, erect and bristly, pubescence dense, especially on the gaster. Punctures finer and closer. Head about as long as broad. Eyes present but small, placed near the middle of the sides, the anterior ocellus is present but very minute. Thorax one and three-quarter times longer than broad, mesonotal suture feebly indicated. Petiole one and one-third times broader than long. Postpetiole and gaster larger, the incisures between the segments

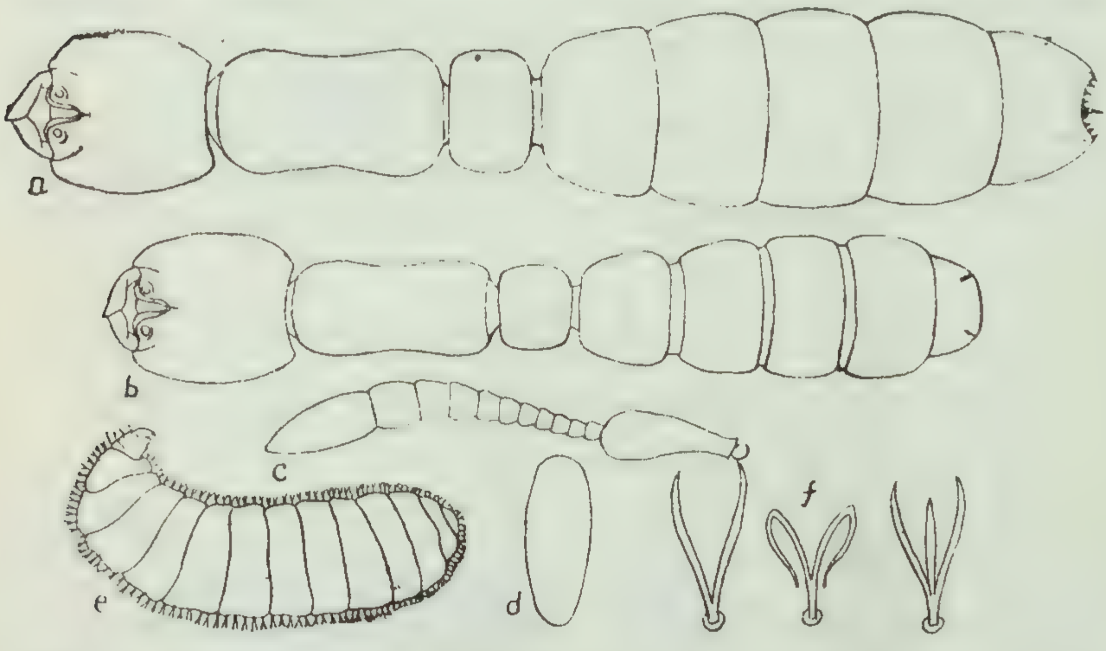


Fig. 2. ***Eusphinctus* (*Nothosphinctus*) *fulvidus*** sp. nov. *a*. Dorsal view of female. *b*. Dorsal view of worker. *c*. Antenna of worker. *d*. Egg. *e*. Larva. *f*. Types of hair on larva.

not pronounced. Pygidium broadly and deeply excised behind, its posterior surface truncated, with submarginate sides, the posterior excision with minute spinules.

Egg. Elongate-ovate, slightly coniform, two and three-quarter times as long as broad. White, with a tinge of yellow.

Larva.—Slender, enlarged at the posterior end, with thirteen distinct segments behind the head. Head as broad as long, with vestigial antennae. Mandibles long and indistinctly dentate. Hairs on the dorsal surface of the anterior eight segments bifurcate almost to their base, short and pointed; on the dorsal surface of the posterior three segments these hairs become long and whip-

like, gradually decreasing in length to the anterior margin of the ventral surface of the anal segment; the hairs on the ventral surface are trifurcate, and extend to the posterior and lateral surface of the head, where they are much shorter than on the body. Colour, yellowish white.

Several larvae, freshly emerged from the eggs, are clothed with long bristle-like hairs, not bifurcate at their tips; these hairs are few and scattered.

Hab.: Western Australia, Mundaring (J. Clark).

Described from a colony containing 680 workers, 1 female, and many eggs and larvæ; no pupæ were found. The nest was under a large stone, and had apparently been in use for a long time, as the excavations were considerable for the size of the ant, extending downward for ten inches, then in a horizontal direction for another six inches, where the queen, and the major portion of the eggs and larvae were found. The same stone also covered a nest of *Myrmecia* (*Pristomyrmecia*) *mandibularis* Sm., the nests practically meeting at one of the side branches, or pockets, of the *mandibularis* nest.

This species is close to *Eusphinctus* (*Nothosphinctus*) *imbecillis, For.*, and to *Eusphinctus* (*Nothosphinctus*) *manni,* Wheeler, The worker differs from the worker of *imbecillis,* in its more rectangular head, more robust and slightly larger size. The female of *imbecillis* is smaller than the female of *fulvidus,* and according to the description, it has no eyes or ocelli. The female of *manni* and *fulvidus* are very similar, but the workers differ considerably.

EUSPHINCTUS (NOTHOSPHINCTUS) SILACEUS sp. nov. (Fig. 3).

Worker: Length 4—5mm.

Reddish yellow; mandibles, carinae, and incisures of the antennal joints darker; hairs yellowish, short, abundant, subappressed; shorter and appressed on the antennae and legs. Head, thorax, petiole and gaster covered with piligerous punctures, which are more numerous on the head than elsewhere. Head longer than broad, as broad in front as behind, sides feebly rounded, posterior border concave, angles rounded; frontal carinae short, erect, truncated and fused behind; surrounding the antennal insertions in front; carinae of the cheeks indistinct; clypeus very short and rounded. Eyes and ocelli absent. Mandibles sub-triangular, deflected, strongly and evenly dentate. Antennae robust, scapes about half the length of the head, gradually thickened to their apex; funicular joints, one to nine broader than long, tenth as long as broad, terminal joint longer than the four preceding joints

together. Thorax fully twice as long as broad, as broad across the pronotum as across the epinotum, flattened above and on the sides; anterior and posterior borders rounded and marginate, epinotal declivity sloping, with marginate sides. Petiole broader than long, broader behind than in front, anterior border straight, angles sharp, lateral and posterior borders slightly convex, corners rounded; in profile flattened above, with straight anterior surface, the ventral surface in front with a long broad tooth-like process.

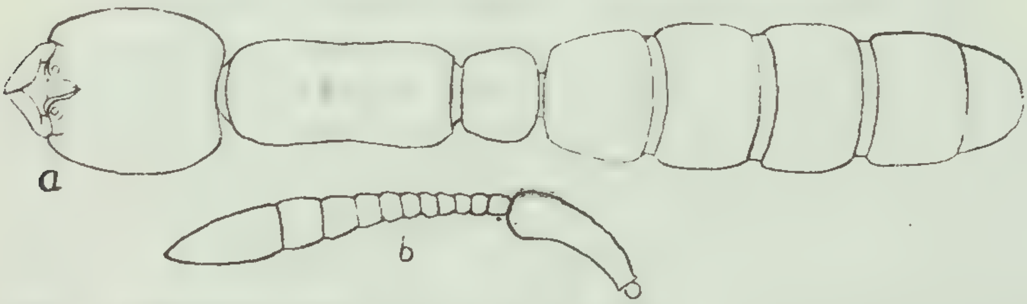


Fig. 3. *Eusphinctus (Nothosphinctus) silaceus* sp. nov. *a*. Dorsal view of worker. *b*. Antenna of worker.

Postpetiole about one and one-fourth times broader than long, broader behind than in front, anterior border nearly straight, angles feebly rounded, sides nearly straight; the ventral surface in front swollen and strongly protuberant. Pygidium flattened above, truncate, entire and blunt at the tip, with a row of spinules along each side, and on the tip. Legs short and stout.

Hab.:—Western Australia. Armadale (J. Clark).

Described from a large number of specimens found travelling in a column alongside a half buried log; the column extended from the log into very dense undergrowth; no nest of the species was found although the ants appeared to be coming from beneath the log. The log sheltered nests of *Camponotus prostans* Forel, and *Iridomyrmex discors* Forel.

PHYRACACES BREVICOLLIS sp. nov. (Fig. 4).

Worker: Length 6.1mm.

Red; antennal incisions and marginations darker; hairs yellow, slender and erect, long and dense on the gaster, shorter and more oblique on the appendages; antennæ with greyish pubescence. Upper surface of the body with sparse piligerous punctures, more numerous on the apical segments of the gaster than elsewhere. Head as long as broad, broader behind than in front, convex above, with truncate occipital region, posterior border concave, angles blunt; frontal carinæ rounded, truncated and confluent behind, extending back to about the middle of the eyes; carinæ of the cheeks

forming a sharp angle, extending back to, and almost encircling, the posterior margin of the eyes; clypeus short and rounded. Eyes large and convex, placed distinctly in front of the middle of the sides; ocelli absent. Mandibles large, triangular, deflected, finely dentate, the external borders concave, coarsely punctate. Antennæ long and robust, scapes more than half the length of the head, gradually thickened to their apex: funicular joints one to ten longer than broad, terminal joint longer than the two preceding joints together. Thorax very short and robust, one third longer than broad, as broad across the pronotum as across the epinotum, slightly constricted in the middle, mesonotal sutures feebly indicated; anterior and lateral borders of the pronotum convex, posterior and lateral borders of the epinotum convex, angles sharp, epinotal declivity straight; all four sides of the dorsum, and the declivity, strongly marginate. Petiole

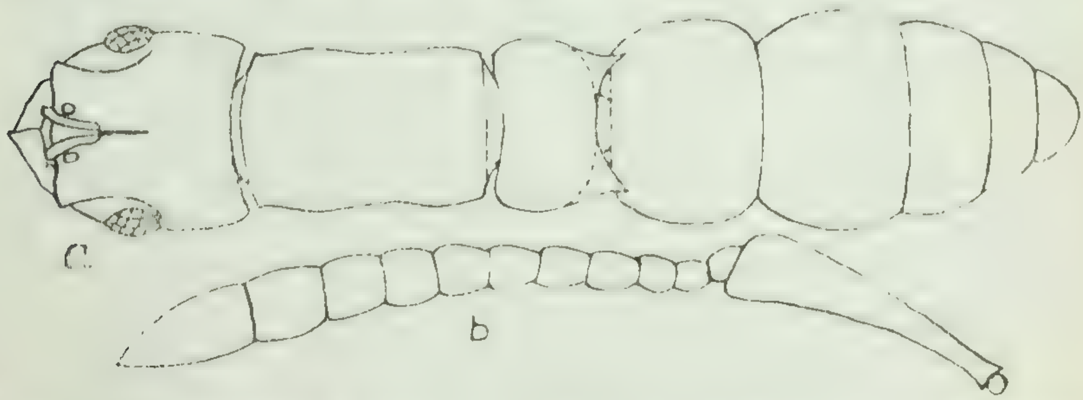


Fig. 4. *Phyracaces brevicollis* sp. nov. *a*. Dorsal view of worker. *b*. Antenna of worker.

distinctly broader than long, broader in front than behind, anterior border concave and feebly marginate, lateral borders convex and strongly marginate, posterior angles produced backward and upward as broad flat teeth; in profile convex above, anterior surface straight, ventral surface with a broad, blunt tooth in front. Postpetiole broader than long, a little broader behind than in front, anterior border straight, angles rounded, sides convex and marginate. First gastric segment fully one and one half times broader than long, broader behind than in front. Pygidium truncate, feebly concave above, marginate and minutely spinulose on the sides and tip. Legs long and stout.

Hab: Western Australia, Kelmscott (J. Clark).

One worker, found running amongst dead leaves.

PHYRACACES CONSTRICTA sp. nov. (Fig. 5).

Female: Length 7.4mm. Ergatoid.

Rich red throughout, marginations darker; hairs yellowish, sparse, fine and erect, longer on the gaster than on the rest of the

body; antennæ and legs with thin greyish pubescence. Upper surface of the body, antennæ, and legs with sparse, fine piligerous punctures. Head longer than broad, as broad in front as behind, occipital border concave, corners sharp; frontal carinæ large, erect, truncated and confluent behind; carinæ of the cheeks bluntly dentate in front, extending back to the anterior margin of the eyes; clypeus very short and broadly rounded. Eyes and ocelli large and convex. Mandibles large and deflected, triangular, finely dentate. Antennæ long and robust, scapes more than half the length of the head; first and second funicular joints longer than broad, third to tenth broader than long, terminal joint longer than the two preceding joints together. Thorax nearly one and one-third times longer than broad, pronotum distinctly broader than the epinotum, mesonotum strongly constricted, sutures feebly indicated, epinotal declivity concave; anterior and lateral borders of the pronotum strongly rounded and marginate, lateral borders of the mesonotum submarginate, lateral and posterior borders of

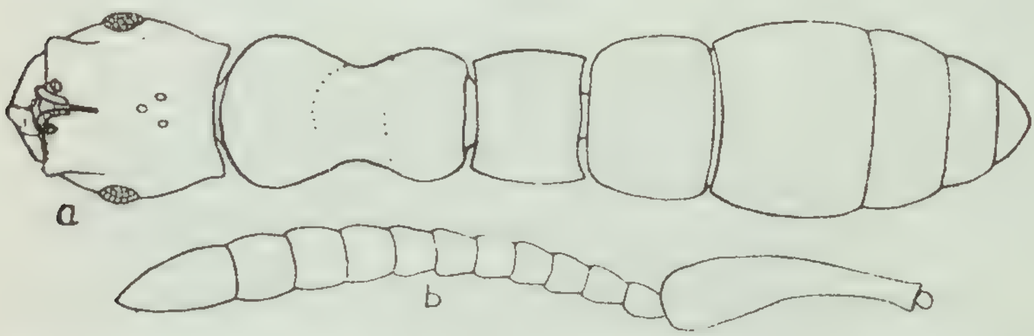


Fig. 5. *Phyracaces constricta* sp nov. female. *a.* Dorsal view. *b.* Antenna.

the epinotum and sides of the declivity strongly marginate. Petiole broader than long, broader behind than in front; anterior border concave and feebly marginate, corners sharp, lateral and posterior borders convex, strongly marginate, the corners produced backwards as sharp teeth; in profile slightly convex above, anterior surface strongly rounded, posterior surface straight; the ventral surface in front with a short blunt tooth. Postpetiole broader than long, broader behind than in front, anterior border straight, strongly marginate, angles rounded, sides convex and marginate. First gastric segment broader than long. Pygidium truncate, feebly marginate and minutely spinulose on the sides and tip. Legs long and slender.

Hab.: Western Australia, Armadale (J. Clark).

Described from a single specimen found in a cell under an old log on the hillside. The appearance of the cell suggested that this female was starting a new colony; it was pear-shaped, about one and one-quarter inches long, and one inch wide at the broad end, and barely one-quarter of an inch deep; the entrance had been

closed with the material excavated. The whole construction closely resembled the cells made by the females of the genus Myrmecia, differing only in size. No eggs were found in the cell.

PHYRACACES GILESI sp. nov. (Fig. 6).

Worker: Length 3.4—4mm.

Blackish; head, antennæ and legs reddish; posterior borders of apical segments of the gaster with a golden yellow tinge; hairs yellow, sparse, rather long and sub-erect; antennæ and legs with fine greyish pubescence. Upper surface of the body with sparse piligerous punctures. Head longer than broad, as broad in front as behind, occipital border concave, angles sharp; frontal carinæ erect, truncate and confluent behind, extending back to about the middle of the eyes; carinæ of the cheeks with a prominent angle, extending back to near the middle of the eyes; clypeus short and rounded. Eyes moderately large and convex, placed well in front of the middle of the sides, ocelli absent. Mandibles triangular, external border slightly concave, finely and evenly dentate. Antennæ

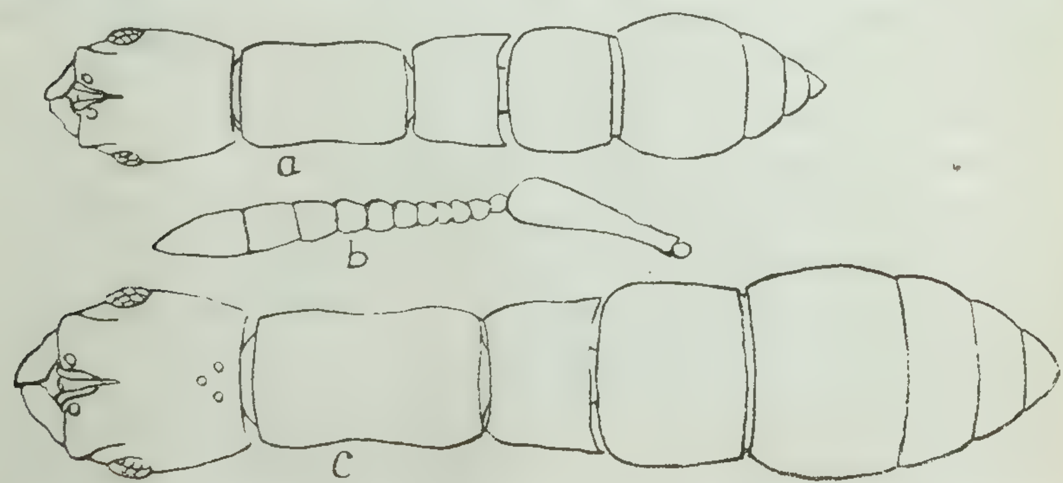


Fig. 6. *Phyracaces Gilesi* sp. nov. *a*. Dorsal view of worker. *b*. Antenna of same. *c*. Dorsal view of female.

robust, the scapes just reach the hind margin of the eyes, enlarged to their apex; first joint of the funiculus as long as broad, second to ninth broader than long, tenth longer than broad, terminal joint pointed, equals the two preceding joints together. Thorax one and one-half times longer than broad, as broad across the pronotum as across the epinotum, slightly constricted in the middle, anterior, lateral and posterior borders, and sides of the declivity marginate; in profile evenly rounded and convex above. Petiole slightly broader than the epinotum, broader than long, and broader behind than in front; anterior border slightly concave, angles sharp, lateral borders convex, posterior border nearly straight, the angles

produced backward and upward as small teeth, all the borders marginate; in profile slightly convex above, the ventral surface in front with a small sharp tooth-like projection. Postpetiole broader than the petiole, slightly broader in front than behind, anterior and lateral borders rounded and marginate. A slight constriction between the postpetiole and the first segment of the gaster, which is broader than the postpetiole, and one and one-fourth times broader than long. Pygidium truncate, feebly marginate and minutely spinulose on the sides and tip.

Female: Length 4.7—5mm. Ergatoid.

Resembles the worker, but with larger eyes, and with large convex ocelli. Thorax slightly more concave on the sides, mesonotal sutures feebly indicated. Gaster much larger. The colour differs slightly; the head, mesonotum, margin of the petiole, anterior and posterior margins of the postpetiole, antennæ and legs reddish yellow; the two apical segments of the gaster golden yellow.

Egg: Elongate-oval, whitish, semi-transparent, two and three-quarter times longer than broad.

Larva: Long and slender, almost cylindrical, slightly thickened at the anterior end, with thirteen distinct segments behind the head. Head small, slightly broader than long, with vestigial antennæ, and short blunt mandibles. Colour dull white; hairs short and bifurcated, except on the head, where they are sparse and not bifurcated.

Pupa: Enclosed in a semi-opaque, parchment-like cocoon.

Hab.: Western Australia, Mundaring (J. Clark).

Described from numerous workers, three females, and many eggs, larvæ and pupæ, taken in a nest under a stone.

This species has been dedicated to Mr. H. M. Giles, the veteran Entomologist of Western Australia.

Phyracaces Newmani sp. nov. (Fig. 7.)

Worker: Length 4.2—5mm.

Red; terminal joints of the antennæ, and legs darker; hairs yellowish, sparse, long slender and erect, more numerous on the gaster than elsewhere, shorter and more oblique on the appendages; terminal joints of the antennæ with greyish pubescence.

Head longer than broad, broader behind than in front, occipital border concave, marginate, corners bluntly rounded; frontal carinæ erect, truncated and confluent behind, extending back to near the middle of the eyes; carinæ of the cheeks with a prominent angle in front, extending back beyond the middle of the eyes, a small

branch extended inward to each antennal fovea; clypeus short and broadly rounded. Eyes large and convex, placed slightly in front of the middle of the sides, ocelli absent. Mandibles large, triangular, deflected, the external borders concave, dentate, coarsely and sparsely punctate. Antennæ robust, scapes reach the posterior margin of the eyes, gradually thickened to their tips; funicular joints, one to three, as long as broad, fourth to eighth slightly broader than long, ninth and tenth longer than broad, terminal joint as long as the two preceding joints together. Thorax one and two third times longer than broad, broader across the pronotum than across the epinotum, narrowed in the mesonotal region; anterior border of the pronotum straight, angles broadly rounded, posterior border of the epinotum slightly concave, angles blunt; in profile the dorsal surface rounded and slightly convex, epinotal declivity slightly convex; all four sides of the dorsum, and sides of the declivity, strongly marginate. Petiole broader than long, broader behind than in front, anterior border

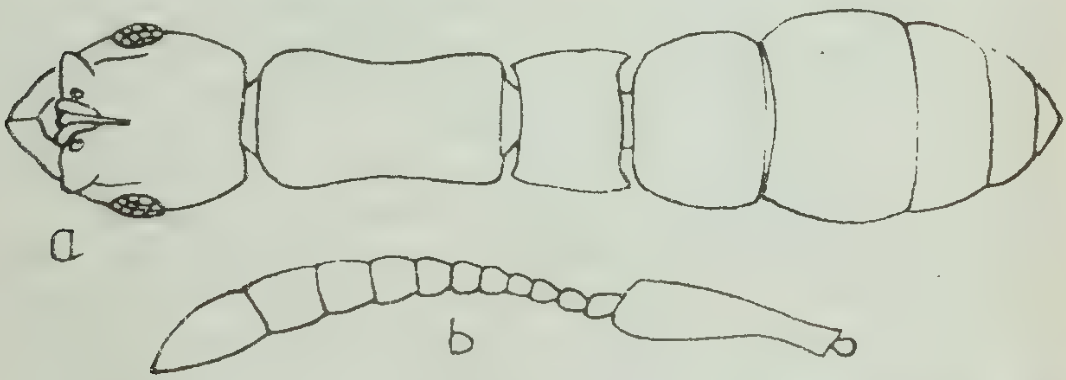


Fig. 7. · *Phyracaces Newmani* sp. nov. *a.* Dorsal view of worker. *b.* Antenna of same.

widely concave, angles sharp, lateral and posterior borders convex, angles produced backward as blunt teeth; in profile cubic, nearly flat above, anterior and posterior surfaces straight, the ventral surface with a short blunt tooth in front. Postpetiole broader than the petiole, broader behind than in front, anterior border straight, angles rounded, sides evenly convex and marginate. A slight constriction between the postpetiole and first gastric segment, which is broader than long, and broader behind than in front. Pygidium truncate, feebly marginate and minutely spinulose on the sides and tip. Legs moderately stout, coxæ of the hind pair with a large translucent lamella at the tip on the inner side.

Hab.: Western Australia, Mundaring (J. Clark).

Described from many workers, forming the major portion of a colony, which was found adjoining a nest of *Myrmecia ludlowi,* Crawley, which was being dug up for observation. The entrance to the nest of *Ph. newmani* was about fifteen inches from the entrance to the *ludlowi* nest, but on digging down eighteen inches into

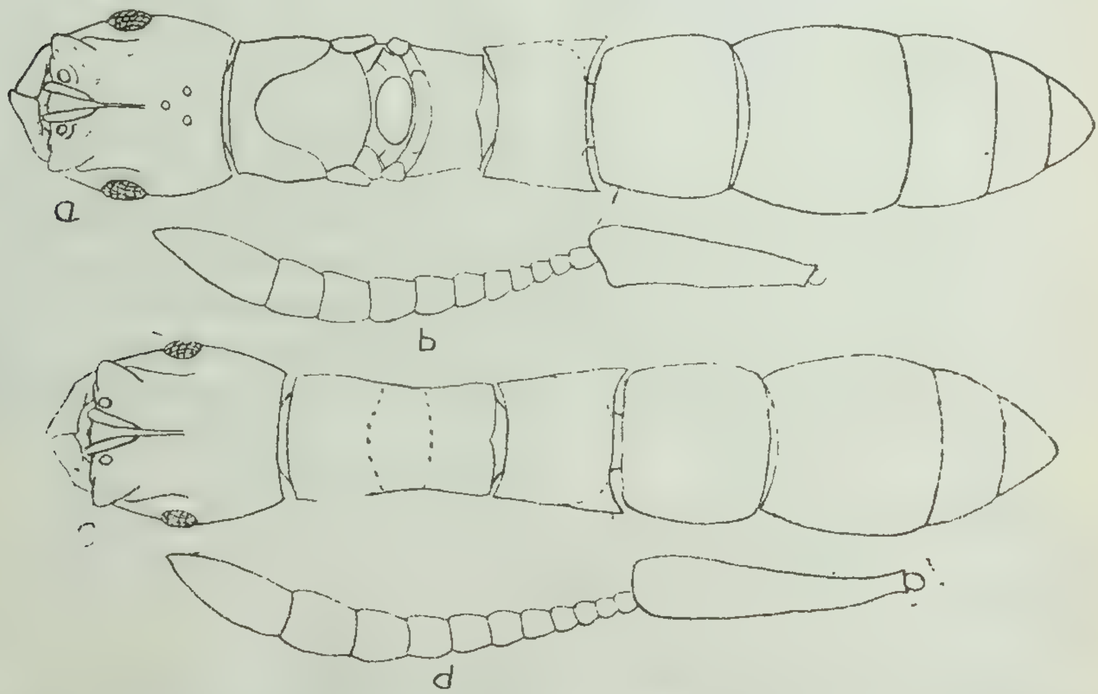
the queen chamber of the *ludlowi* nest it was found that both nests practically met at this point, suggesting that the colony of *newmani* was parasitic on the brood of *ludlowi,* more so as the tunnels of *newmani* connected with the cells of *ludlowi* at various places. The small size of the *Phyracaces* tunnels made it impossible for the large *Myrmecia* to follow in defence. This species has been dedicated to Mr. L. J. Newman, Economic Entomologist of Western Australia.

PHYRACACES PUNCTATISSIMA sp. nov. (Fig 8).

Worker: Length 6—7.2mm.

Bright castaneous throughout, with only the mandibles, the edge of the frontal carinæ, the marginations of the head and body darker; hairs yellowish, sparse, long, slender and erect, more numerous on the gaster than elsewhere, shorter and more oblique on the appendages; antennæ, dorsal surface of the petiole and postpetiole with conspicuous greyish pubescence. Head longer than broad, as broad in front as behind, convex above with truncated occipital region, occipital broader, slightly concave, marginate, angles sharp; frontal carinæ large, erect, truncated and confluent behind, extending back to the middle of the eyes; carinæ of the cheeks with a prominent angle in front, extending back to the posterior margin of the eyes, a short branch directed inward to each antennal fovea; clypeus short, broadly rounded. Eyes moderately large and convex, placed slightly in front of the middle of the sides, ocelli absent. Mandibles triangular, deflected, external borders nearly straight, coarsely and sparsely punctate. Antennæ robust, scapes reach to the middle of the eyes, gradually thickened to their tips; funicular joints, two to eight, broader than long, ninth and tenth longer than broad, terminal joint tapering and pointed, longer than the two preceding joints together. Thorax narrower than the head, one and two-thirds times longer than broad, broader across the pronotum than across the epinotum, narrowed in the middle, mesonotal sutures feebly indicated; in profile feebly convex and rounded, epinotal declivity abrupt, concave; anterior border of the pronotum convex, angles sharp, posterior border of the epinotum straight, slightly excised in the middle, angles sharp; borders of the pronotum and of the epinotum and sides of the declivity strongly marginate, lateral borders of the mesonotum feebly marginate. Petiole broader than long, broader behind than in front, its anterior border concave, with sharp pointed corners, lateral and posterior borders straight with the corners produced backward as broad sharp teeth, the lateral borders marginate; the dorsal surface densely covered with very small punctures; in profile feebly convex

above, the anterior surface convex, the ventral surface with a strong tooth in front. Postpetiole a little broader than the petiole, very slightly broader than long, slightly broader behind than in front, anterior and lateral borders slightly convex, the corners rounded; the dorsal surface densely covered with very small punctures. A slight constriction between the postpetiole and the first segment of the gaster. Pygidium marginate and minutely spinulose on the sides and tip. Legs moderately long and stout.



Fig, 8. *Phyracaces punctatissima* sp. nov. *a.* Dorsal view of female. *b.* Antenna of female. *c.* Dorsal view of worker. *d.* Antenna of worker.

Female: Length 8—8.3mm.

Resembles the worker but has larger eyes, ocelli, and a different thorax. The latter, not so broad as the head, is one and three-quarter times longer than broad, with distinct pronotal, mesonotal, scutellar, metanotal, parapteral, sternal and mesepimeral sclerites, though there are no traces of wing stumps. The mesonotum is twice as broad as long. Gaster twice as long as broad. Sculpture, pilosity and colour similar to those of the worker.

Hab: Western Australia, Mundaring (J. Clark).

This species comes near *Ph. clarki*, Crawley, but can be readily distinguished by its more slender build, and very different petiole and postpetiole.

The colony obtained consisted of 160 workers, four females, and a large number of larvæ and pupæ. The nest was underground and extended down nineteen inches, where the females and brood were obtained. This ant has a peculiar habit of turning its abdomen up over its back when running, and looks very much like a red Staphylinid beetle; it hunts singly, and in all directions near the nest.

PHYRACACES RUFICORNIS sp. nov. (Fig. 9).

Worker: Length 6—6.8mm.

Black; antennæ and tarsi reddish, mandibles, femora, tibia, pygidium and sting brownish; hairs yellowish, suberect, long and pointed, more numerous on the gaster than on the rest of the body, shorter and finer on the antennæ and legs. Head longer than broad, as broad in front as behind, slightly constricted in the occipital region, convex above, occipital border widely concave, strongly marginate, corners acutely produced; frontal carinæ erect, truncated and confluent behind; carinæ of the cheeks with a prominent tooth or angle, extending backward to near the middle of the eyes, a small branch directed inward to each antennal fovea; clypeus short and rounded. Eyes moderately large, placed in front of the middle of the sides, ocelli absent. Mandibles triangular, deflected, external borders nearly straight, dentate, coarsely and sparsely punctate. Antennæ long and robust, scapes fully half the length of the head, gradually thickened to their

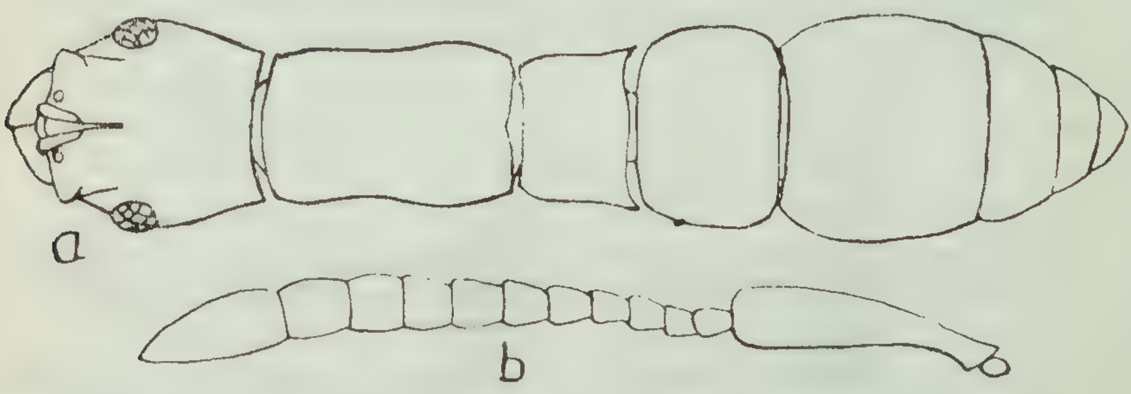


Fig. 9. *Phyracaces ruficornis* sp. nov. *a*. Dorsal view of worker. *b*. Antenna of worker.

apex; funicular joints, second to ninth, broader than long, tenth as long as broad, terminal joint tapering, pointed, as long as the two preceding joints together. Thorax a little more than one and a half times as long as broad, epinotum very slightly broader than the pronotum, slightly constricted in the mesonotal region, mesonotal sutures feebly indicated; anterior border of the pronotum convex, corners sharp, posterior border of the epinotum nearly straight, slightly excised in the middle; all four sides of the dorsum, and sides of the declivity, strongly marginate; in profile, evenly convex above, with straight, nearly vertical declivity; the ventral surface in front with a sharp tooth. Petiole broader than long, slightly broader behind than in front, anterior border widely concave, lateral and posterior borders convex, the angles produced backward as small flattened, acute teeth, all four sides marginate; in profile the surface and the anterior declivity are convex, sides nearly straight,

the ventral surface in front with a sharp tooth projecting slightly backward. Postpetiole about one and one-third times as broad as long, slightly broader behind than in front, anterior and lateral borders convex and marginate. First gastric segment broader than the postpetiole, broader than long. Pygidium truncate and bluntly pointed at the tip, concave above, marginate and minutely spinulose on the sides and tip; posterior borders of the gastric segments, and sides of the pygidium, densely and finely punctate.

Larva: Long and slender, with vestigal antennæ.

Pupa: Enclosed in reddish-yellow, parchment-like cocoon. The pupæ of several males were found in their cocoons, but they were not fully matured. These males varied in size from 5.5 to 6mm. The antennæ are thirteen jointed. Head and body black, antennæ red.

Hab: Western Australia: Armadale, Mundaring (J. Clark).

Described from several workers forming the major portion of a colony found under a piece of rotten timber near Mundaring; no female was found in the nest.

Three specimens found running amongst large stones at Armadale belong to this species; they are slightly larger than the typical form, but are otherwise identical.

PHYRACACES SIMMONSAE sp. nov. (Fig. 10).

Worker: Length 4—4.2mm.

Red; base of scapes, incisures of the funicular joints, base of the femora and tibia reddish-brown, marginations black; hairs yellowish, erect, rather long and pointed, sparse, not longer and denser on the gaster than on the rest of the body; antennæ and legs with rather long, appressed, greyish pubescence. Head longer than broad, as broad in front as behind, occipital border widely concave, marginate, angles sharp; frontal carinæ erect, extending back to the eyes; carinæ of the cheeks forming a prominent blunt tooth in front, and extending back beyond the middle of the eyes; clypeus short and rounded. Eyes large, slightly flattened, placed slightly in front of the middle of the sides, ocelli absent. Mandibles large, external borders nearly straight, dentate, coarsely and sparsely punctate. Antennæ robust, scapes reach the posterior margin of the eyes, gradually thickened to their tips; funicular joints one to nine a little broader than long, tenth as broad as long, terminal joint tapering and pointed, longer than the two preceding joints together; base of the antennal depression reticulate-punctate, with a few rugæ on the side of the depression,

the rest of the head with small, scattered, piligerous punctures. Thorax a little more than one and a half times longer than broad, as broad across the pronotum as across the epinotum, slightly narrowed in the middle, anterior and lateral borders of the pronotum strongly marginate, lateral borders of the mesonotum, lateral and posterior border of the epinotum submarginate, epinotal declivity sharply marginate; in profile the dorsal surface feebly convex. Petiole one and a half times broader than long, anterior border concave, the lateral borders gently rounded to the posterior third, then abruptly rounded to the posterior border, which is very short; all four sides of the dorsum strongly marginate; in profile cubic, dorsal

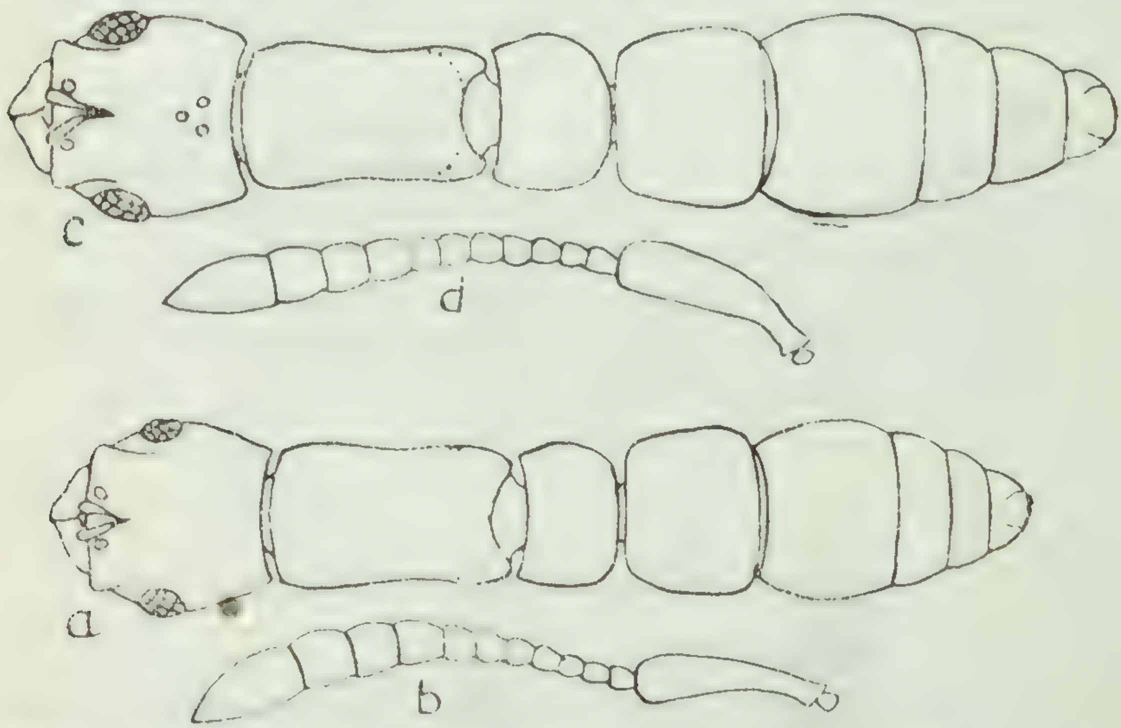


Fig. 10. *Phyracaces Simmonsae* sp. nov. *a.* Dorsal view of worker. *b* Antenna of same. *c.* Dorsal view of female. *d.* Antenna of same.

surface slightly convex, anterior surface straight and at right angles to the dorsal surface, posterior surface convex; the ventral surface with a projection, more than half the length of the surface, from which arises a short blunt tooth, directed backward. Postpetiole broader than long, broader behind than in front, sides slightly convex, anterior and lateral borders strongly marginate. First gastric segment broader than long, broader behind than in front, sides strongly convex. Pygidium with a large concave depression on its dorsal surface, marginate and minutely spinulose on the sides and tip.

Female: Length 4.8mm.

Differs from the worker in its much larger size, larger and more convex eyes, and presence of ocelli. Head more rectangular, and

slightly broader behind than in front, broader than the pronotum. Pronotum slightly broader than the epinotum. Petiole broader than the thorax, and one and one-third times broader than long. Postpetiole and gaster separated by a small constriction, the latter one and three-quarter times longer than broad. Sculpture and pilosity similar. Head, thorax, petiole and postpetiole rich red, gaster yellowish-red.

Larva: Long and slender, subcylindrical, slightly thickened to the posterior end, with thirteen distinct segments behind the head, which is short and broad. Hairs short and stout, bifurcated to one-third of their length. Colour dull white.

Pupa: Enclosed in reddish-yellow, parchment-like cocoon. The pupæ of two males were found in their cocoons, but were not fully developed. The males measure 4.7–5.3mm.; the antennæ, which are thirteen jointed, reach to the first gastric segment. Eyes and ocelli large.

Hab: Western Australia; Denmark (Miss E. Simmons), Mundaring (J. Clark).

Described from a small colony taken near Mundaring, and a single worker obtained by Miss Simmons at Denmark in October, 1922. The specimen from Denmark no doubt formed part of a raiding party, as the colony taken at Mundaring was noticed whilst its members were raiding a nest of *Cremastogaster rufotestaceus*, Mayr, and were traced to their nest, about thirty yards away. The *Phyracaces* were taking both larvæ and pupæ from the *Cremastogaster* nest, and apparently, got very little opposition from the ants of the latter nest, who seemed to concentrate their energy to removing their brood. The *Phyracaces* did not move in a body, but worked much as do the species of *Iridomyrmex*, a constant stream of ants coming and going between the two nests with usually a gap of many inches between the workers. The nest of *Ph. simmonsae* was very inconspicuous, being indicated merely by a small hole, less than one quarter of an inch in diameter, on level ground. This nest extended underground for eleven inches, ending in an elongate chamber, where the female and her brood were found. A number of *Cremastogaster* larvæ and pupæ were also found in the chamber. This species has been dedicated to Miss E. Simmons, an enthusiastic naturalist in the Denmark district.

CONTRIBUTIONS TO THE FLORA OF WESTERN AUSTRALIA, No. 3.

By Charles A. Gardner, Forests Department, Perth.

(*Read* 8th May, 1923.)

My two earlier papers dealt only with plants which were new to science, but in the present paper I have begun a series of systematic notes, recording new localities, or adding information concerning the species dealt with, which to my knowledge has not previously been published. These notes commence with the *Gymnospermae,* omit the *Monocotyledoneae,* and start again with the *Casuarinaceae.*

It is intended in subsequent contributions to follow out this method, following Engler's system.

This paper also contains descriptions of three new species.

Coniferae.

Callitris Roei, Endl.

A small tree or shrub of 12 to 15 feet in height, densely branched with short horizontal spreading branches. Male amenta 4 mm. long, shortly cylindrical, brownish-yellow, terminating the short branchlets, the staminal scales in whorls of three, broadly ovate with a short, almost acute apex; anther-cells 2.

I collected this rare species from two localities, viz., six miles North of Bluff Knoll, Stirling Range, in gravelly soil on rising ground in thickets of mallee, and at Bendering, near Kondinin, in arid sandy soil on plains. The fruiting cones are densely clustered on the lateral branches, and are quite smooth before opening, the dorsal conical protuberance acute. The locality of Bendering extends the range of this species to a distance of over a hundred miles north of the previously recorded stations.

Casuarinaceae.

Casuarina Dorrienii, Domin.

This species was collected near the summit of Warrungup Hill, Stirling Range. The whorls are 8-10-merous (Domin states 9-merous), and the cones are occasionally more cylindrical than figured in his description. It is a robust shrub of 6-10 feet with widely spreading branches. I consider this to be a form of *Casuarina Huegeliana,* but although the locality is exactly that of A. Smith-Dorrien, I have not seen Dr. Domin's specimens.

Casuarina distyla, Vent.

I again collected this species at Borden, and in Toll's Pass, Stirling Range. It attains a height of 20 feet, but is always a shrub with erect virgate branches. The cones may be shortly cylindrical, and the male amenta terminate the branchlets, but these have not been seen in a mature state.

Casuarina lepidophloia, F. v. M.

The species occurs abundantly on the gravelly plains between Coolgardie and Kalgoorlie. The prominent villous bracteoles easily distinguish it from *C. glauca* to which it is closely allied. It occurs as a tree of 20-35 feet with a reddish timber.

Casuarina humilis, Otto et Dietr.

A robust form of this species is common around the Stirling Range. The cones may attain a length of over 4 cm., the branches are much stouter and more erect than those of the typical form. The shrub seldom exceeds 4 feet in height.

Casuarina grevillioides, Diels.

The cones of this species have not been previously described: Fruiting cones sessile, either on the branches or the woody stock, solitary or densely clustered, ovoid, lateral, 4-merous, 1.8 cm. long and 1.5 cm. diameter. Bracts tomentose, trianguar-cuneate, broad on the summit with a fine terminal point, convex and keeled. Bracteoles much protruding, obtuse, prominently keeled, minutely tuberculate, the dorsal protuberance small, triangular, shortly tomentose. Achenes light yellow, ovate, thick, smooth and glabrous, the wing rudimentary and triangular at the base ot the black persistent protruding style, the whole achene enveloped in numerous golden-yellow hairs which arising from the base exceed it in length.

This interesting species was again collected on the summits of low stony hills, 1½ miles North-East of Mogumber among low shrubs, where Diels collected it in 1903.

Casuarina decussata, Benth.

I collected this species near the summit of Bluff Knoll, Stirling Range, at an altitude of over 3,000 feet. The trees at this altitude, although possessing a trunk of over fourteen inches in diameter, did not exceed ten feet in height.

PROTEACEAE.

Petrophila scabriuscula, Meissn.

This species occurs near Tammin in arid sandy soil. It differs chiefly from *P. ericifolia* in its broader cone-scales.

P. Serruriae, R. Br.

An erect shrub of 2-4 feet, common in the declivities of the Stirling Range. The flowers are a pale yellow, and the small cones usually clustered into a terminal leafy spike. Fl. m. October-November.

P. striata, R. Br.

A rigid shrub of 2-3 feet with spreading intricate branches and a dark coloured bark. Flowers yellowish-white. Bracts reddish-brown, broadly ovate and obtuse.

Wagin, a common species occurring on gravelly hills in open forests of wandoo. Fl. m. October-November.

Isopogon latifolius, R. Br.

This conspicuous species extends to the summits of the highest peaks of the Stirling Range. Cones 2½ inches diameter, the flowers deep purple. The species occur in stony soil or rock crevices, flowering in October and November.

I. buxifolius, R. Br. var. *obovatus,* R. Br.

The species is a low spreading shrub of 2-3 feet. Flowers woolly-white.

Cranbrook, in arid sandy soil on plains, fl. m. March.

I. scabriusculus, Meissn.

A small rigid shrub of 1-2 feet with erect branches and leaves. Leaves pungently acute; flowers pink.

Yorkrakine, in yellow gravelly soil among other low shrubs, flowering August-September.

Adenanthos cuneata, Labill.

This species is at once conspicuous through the colour of its leaves, which are a silvery grey-green suffused with a dull purple-brown near the apex. Flowers red.

Common in the jarrah forests between Albany and the Stirling range, fl. m. December-January.

A. Drummondii, Meissn.

I found this handsome little species with bright scarlet flowers in flower at Mogumber early in January. Attains a height of 2 feet with erect leafy branches.

Simsia simplex, Lindl.

Stem subterranean. Flowers sulphur-yellow. The species extends eastwards to Bendering, in arid sandy soil on open plains, flowering October and November.

Conospermum amoenum, Meissn.

An erect shrub of 1-2 feet in height, densely branched with erect branches, the stem simple at the base and expanded with a thick

swollen corky bark at the ground surface. Leaves linear-terete, but flattened slightly or grooved above. Flowers lavender-blue. Bendering, a common plant in sandy gravelly soil among low shrubs, fl. m. October-November.

In my specimens the bracts are less than half as long as the perianth-tube.

C. Brownii, Meissn.

1-2 feet high, leafy only in the lower parts. Flowers white in dense terminal panicles, the young buds pale blue.

Kellerberrin and Bendering, in sandy soil on open plains, fl. m. October-November.

C. caeruleum R. Br., var. *marginatum*, Benth.

Ludlow, in sandy soil in the jarrah forest, fl. m. August.

C. densiflorum, Lindl.

Stems spreading at the base, at length erect. Flowers white, the rhachises thickened and hirsute.

Moore River, Mogumber, in gravelly soil in the Wandoo forest, fl. m. December.

Conospermum Dorrienii, Domin.

A shrub of 3 feet with erect leafy branches, growing on the stony slopes of Warrungup Hill, Stirling Range. Fl. m. October (Mrs. T. Pelloe).

Conospermum Eatoniae, E. Pritzel.

This species was collected on the sandplain near Tammin, in arid sandy soil, fl. m. August-September.

My specimen differs from those of E. Pritzel only in being a decumbent shrub with flexuose-divaricate branches, whereas the type is given as an erect shrub. Fl. pale blue.

C. flexuosum, R. Br.

Common in the tuart forest around the Capel and Ludlow Rivers, in sandy loam, fl. m. August.

Franklandia fucifolia, R. Br.

An inhabitant of the sandy plains around the Stirling Range northwards to Tambellup and westwards to the Bow River. Flowers pale yellow, spotted with red. Fl. m. April-July.

Persoonia Saundersiana, Kipp.

A shrub or small tree of 10-18 feet with erect virgate branches; bark ash-grey, smooth; timber soft and white. Flowers lemon-yellow.

Tammin, in yellow sandy soil on yellow gravelly soil on plains fl. m. September. Also near Wyalcatchem.

P. striata, R. Br.

A perfectly glabrous shrub of 3-4 feet of spreading habit with rigid wiry branches. Leaves spirally twisted. Flowers yellow, anther-appendages not very long.

Westonia, in yellow sandy gravelly soil in thickets. Fl. m. November; Bungulla, in similar situation.

P. quinquenervis, Hook.

Leaves erect, rigid, the veins anastomosing. Flowers yellow. A common shrub in the York district, known as "Kauberry."

P. longifolia, R. Br.

A tree of 10-20 feet. Trunk to 8 feet and 8ins. diameter, bark purple, flaky; timber red. Flowers yellow. Fruits purple when ripe. The common "Native Plum." Fl. m. November-December.

Xylomelum occidentale, R. Br.

"Native Pear." A tree attaining 25 feet, with a dark grey fibrous stringy bark. Timber dark brown, beautifully grained. Flowers sulphur-yellow, or yellowish-white. Bracts densely tomentose, not persisting until the flower opens. Style shorter than the perianth, slender, the style-end club-shaped, 5-furrowed.

Keysbrook to Bunbury and Collie, flowering in January. Fruit 3-6ins. long, closely ferruginous-tomentose.

X. angustifolium, Kipp.

"Sand-plain Pear." A shrub of 10-15 feet with a short stout trunk of 2-3 feet in height, and numerous erect or spreading branches. Timber pale, soft; bark light grey. Leaves light green, tapering and uncinate. Fruits much smaller than in X. *occidentale,* not falcate.

Watheroo, in sandy soil, with *Jacksonia eremodendron.* Yorkrakine and Kellerberrin, in sandy soil on open plains. Fl. m. January.

Lambertia inermis, R. Br.

Albany to Broome Hill, in arid sandy soil; a shrub of 10-20 feet. Flowers red or yellow. "Wild Honeysuckle."

L. ericifolia, R. Br.

A shrub of 10-20 feet with slender virgate branches. Fl. orange-red. Confined to the Stirling Range and eastwards to Bremer Bay. Fl. m. April-May.

L. ilicifolia, Hooker.

Gravelly thickets around Wagin, Fl. m. September.

Follicle ovate, ¾in. long, armed with stout tubercular spines, with a prominent terminal horn to each valve.

Grevillea pectinata, R. Br.

A low spreading shrub of 12-20ins. in height, spreading to a diameter of 3 feet, the branches rigid. Leaves (in my specimens) all with 7 segments, almost pungent. Flowers crimson-red. Ovary-stipes long and slender.

Wagin, in gravelly soil. Fl. m. October-November.

G. Thelemanniana, Endl.

A much branched shrub of 2-3 feet. Flowers bright scarlet. Common on the coastal limestone near Fremantle. Fl. m. Sept.

G. Hookeriana, Meissn.

A pyramidal shrub of 4-12 feet with horizontally spreading short branches. Adult leaves silvery-sericeous with a short pubescence, or nearly glabrous. Flowers orange-scarlet. Perianth-tube not 3 lines long. Ovary shortly, but distinctly stipitate. Fruit ovate-acuminate, more than 1 inch long.

Bendering, in arid sandy soil, extending to Harrismith, on open plains. Fl. m. October-November.

G. Pritzelii, Diels.

A low, dense, spreading shrub with rigid branches, 4-5 feet high.

Dowerin, Wyalcatchem, Yorkrakine and Kellerberrin, in yellow sandy soil among other dense shrubs. Fl. m. October-November.

G. pterosperma, F. v. M.

A pyramidal shrub or small tree of 10-15 feet with horizontal branches. Racemes dense, flowers white.

Yorkrakine, in yellow sandy soil. Fl. October-November. Also at Carrabin in similar situation.

G. eriostachya, Lindl.

Mogumber and Watheroo, in sandy soil among low shrubs. Fl. m. December-January.

Six-ten feet high, stems erect, racemes erect; the flowers lemon-yellow.

G. excelsior, Diels.

A shrub or small tree pyramidal in shape, 8-16 feet high, with horizontally spreading branches. Flowers golden-yellow, in dense, usually spreading racemes. Timber soft and pale.

Tammin, Yorkrakine, Wyalcatchem, Bencubbin, Westonia and Coolgardie, in yellow sandy soil on plains. Fl. m. October-November.

This inland eremaean species differs from *G. eriostachya,* according to Diels, in habit, shorter racemes and fruit, and the leaves on the rhachis. My specimens show that the racemes are variable in length with regard to both species. I can find little or no difference in the fruit, and therefore the differences are reduced to habit and

rhachis. The rhachis of *G. excelsior,* however, possesses no leaves; the leaves are at the summit of the branchlets, and the racemes are terminal. The difference in habit therefore appears to be the only constant feature.

G. bipinnatifida, R. Br.

This handsome species is common in the granites of the Darling Range. Fl. m. June-October, or more or less throughout the year. Its large glaucous leaves and large dull red flowers render it a conspicuous species.

G. Wilsoni, A. Cunn.

A bushy shrub of 2-4 feet with erect branches. Fl. crimson.

Perth to Waroona, common in gravelly soil at the foot of the Darling Range. Fl. m. September-October.

G. Brownii, Meissn.

A straggling shrub of 1-3 feet. Flowers dull red. Gravelly hills, Porongorup Range. Fl. m. March.

G. fasciculata, R. Br.

A small erect shrub of 1-2 feet. Flowers dull red. Stirling Range, in stony soil at the foot of Toolbrunup. April, 1923 (in full flower).

G. haplantha, F. v. M.

A small shrub of 1-3 feet densely branched with erect branches. Leaves erect, glaucous, minutely silvery-pubescent, even when old. Flowers orange-red.

Yorkrakine, in yellow sandy soil in thickets. Fl. June-August.

G. acauria, F. v. M.

Quite glabrous except the flowers. A small wiry spreading shrub of 3-4 feet. Flowers crimson, glabrous without.

Kununoppin, Nungarin and Yorkakine, in loamy soil in open forests of Salmon Gum (*Eucalyptus salmonophloia*). Fl. m. June-August.

G. quercifolia, R. Br.

A trailing or prostrate shrub with weak ascending branches. Flowers pink-purple. Fruit ovoid, about ½ inch long, thickly beset with acute tubercles, the style persisting and broadened into an acuminate appendage.

Gravelly soil, Armadale, Waroona and Collie. Fl. m. September-October; fruiting in January.

G. Huegelii, Meissn, var. *simplicifolia,* F. v. M.

A stout shrub of 8-15 feet with rigid erect branches. Bark fibrous, dull grey, the branchlets brown and shining. Flowers scarlet.

Laverton, in gravelly soil, in open spaces. Fl. m. September-November. Also near Kalgoorlie.

G. occidentalis, R. Br.

A small bushy shrub of 1-2 feet in height. Flowers yellowish-white. Armadale, in clay soil. Fl. m. October.

G. oxystigma, Meissn.

A dense bushy shrub of 2-3 feet with erect branches. Flowers white.

Mogumber, in sandy gravelly soil, on the foothills of the Darling Range. Fl. m. July-August.

G. uncinulata, Diels.

1-2 feet high, with rigid erect or spreading branches. Leaves linear, with closely revolute margins, glabrous on both pages. Flowers yellowish-white. Fruit oblong-ovoid, pubescent.

Goomalling, in yellow gravelly soil. Fl. m. August. Tammin (where Dr. Pritzel collected it) in fruit m. October.

G. Endlicheriana, Meissn.

6-10 feet high, branching from the base with slender virgate branches, leafy only in the lower parts. Flowers pink or white.

Mogumber, Swan View, Red Hill and Darlington, in sandy loam among granite rocks. Fl. m. July-September.

G. Manglesioides, Meissn.

A bushy shrub of 6-15 feet. Flowers white.

Ludlow River and Vasse River, Busselton, in sandy soil along the banks of watercourses. Fl. m. July.

G. diversifolia, Meissn.

Helena River, Midland Junction. A shrub of 10-20 feet with willow-like flexuose branches.

G. eryngiodes, Benth.

Branches ascending or erect, 1-3 feet high, leafy only in the lower portions, the leaves large and glaucous blue in colour. Bracts yellow-green. Flowers yellow, suffused with purple. Fruits ovoid, flattened, viscid, 5 lines diameter, brown.

Carrabin, in arid sandy soil on open plains, Westonia, Kellerberrin and Bendering, in similar situations. Fl. m. November.

G. crithmifolia, R. Br.

King's Park, Perth. A bushy shrub of 2-6 feet densely branched with erect branches. Flowers white. Fl. m. August-October.

G. synapheae, R. Br.

Branches trailing for several feet, or ascending. Flowers pale yellow. Moore River, Mogumber, in gravelly soil. Fl. m. July.

G. didymobotrya, Meissn.

This species, a shrub of 6-10 feet, erect with slender erect branches, inhabits the yellow sandy soil of the sand plains between Tammin and Coolgardie, flowering in October and November.

G. nematophylla, F. v. M.

A small tree of 10-25 feet with a trunk of 4-6 ins. diameter. Bark dark grey, longitudinally fissured. Timber pale red. Flowers white or pink. Fruits ovoid, compressed, about ½in. long.

"Water Bush" of the Eastern Goldfields, extending from Norseman to Coolgardie and Menzies, in sandy gravelly soil in open places. Fl. m. December-January.

G. Purdieana, Diels.

Bencubbin, in arid sandy soil, a small tree. Fl. m. October.

G. paradoxa, F. v. M.

A shrub of 4-8 feet, with erect branches, densely bushy. Leaves pungently acute. Flowers deep pink.

Tammin, Wyalcatchem, Mount Marshall, Yorkrakine, Coolgardie, and Westonia, in yellow sandy gravelly soil usually in thickets of Melaleuca and Casuarina. Fl. m. August-October.

G. petrophiloides, Meissn.

A shrub of 5-8 feet, the branches spreading, at length erect. Flowers rose-pink, the limb of the perianth and stigmatic cone pale green.

This handsome species occurs between Goomalling, Tammin and Nungarin, in yellow gravelly soil usually in thickets with *G. paradoxa,* F. v. M.

G. apiciloba, F. v. M.

This species, which undoubtedly has its affinity in *G. Pritzelii,* Diels, is a characteristic shrub in the yellow sandy gravelly thickets around Carrabin. Fl. m. October.

G. integrifolia, Meissn, var. *incurva,* Diels.

An erect wiry shrub of 4-12 feet, the branches and leaves densely sericeous with a close pubescence. Bark of the lower branches and stem light brown, smooth and shining. Flowers light yellow.

Tammin and Kellerberrin, in arid sandy soil. Fl. m. October-November.

G. ornithopoda, Meissn.

A willow-like shrub of 10-15 feet. Bark green and thin. Flowers white. Helena River, Mundaring Weir, on the banks of the river, forming dense thickets. Also at Jarrahdale, in similar situation. Fl. m. June-July.

G. amplexans, F. v. M.

Naraling, near Geraldton (A. M. Dillon).

Hakea Cunninghamii, R. Br.

Beria, in sandy loam, in low-lying places in the mulga bush. Leaves light green, rigid, 8-11 ins. long. Flowers sulphur-yellow, the styles crimson.

Hakea cyclocarpa, Lindl.

This common species rarely seen in flower occurs between Armadale and Collie, a small shrub of 4-6 feet, in gravelly soil, known under the name of "Wild Bean."

H. crassifolia, Meissn.

A tall shrub attaining a height of 20 feet or more. Branches rigid and erect. Flowers yellow.

Sandplains around the Stirling Range, fl. m. October-November.

H. Brownii, Meissn.

A small dense widely branched shrub of 4-8 feet.

Wagin, in sandy gravelly soil; Warrungup Hill, in sandy stony soil.

H. eriantha, R. Br.

What appears to be this species was collected at Pemberton. The fruits, however, are absent. A shrub of 15 feet with slender branches. Flowers white, the styles dark-coloured.

The leaves and flowers agree very closely with the description given.

This species has not been previously recorded from Western Australia.

H. trifurcata, R. Br.

Thus bushy species, a shrub of 4-8 feet, is easily recognised by reason of its leaves, which are of two types; linear-terete, divided into slender segments, and flat pale green ovate concave leaves, usually on the older branches. The flowers are white.

The species is common in the Darling Range, extending to the South-West districts and Narrogin. Fl. m. August-September.

H. platysperma, Hook.

A low rigid shrub of 3-5 feet with spreading branches. Flowers yellow.

Wyalkatchem, North Kellerberrin, and Tammin, in arid sandy soil, fl. m. August.

H. Preissii, Meissn.

A shrub or tree of 10-25 feet with a trunk of up to 10 ins. diameter. Flowers greenish-yellow. Typical of swampy clay flats along the Great Southern Railway, and on the coastal plain between Perth and Busselton, known as "Needle tree." Fl. m. November-December.

H. amplexicaulis, R. Br.

Darling Range between Darlington and Collie, a small straggling shrub of 4-8 feet with a yellowish bark. Of the habit of *H. glabella,* it can be easily distinguished by its longer smooth fruits.

H. glabella, R. Br.

"Prickly Pear." Usually a shrub or small tree of 12-20 feet, with a rough grey persistent bark. Flowers white, sweetly scented. Common along the Great Southern Railway, in the wandoo (*Eucalyptus redunca*, var. *elata*) forest, in sandy loam, fl. m. August-October.

The species along the coastal plain is seldom above 10 feet high. Here it is typically a low spreading shrub.

H. Pritzelii, Diels.

A low trailing shrub. Warrungup Hill, Stirling Range, in fruit m. April.

H. cristata, R. Br.

Red Hill, Darlington and Mundaring Weir, fl. m. June.

Appears to be confined to this district.

H. linearis, R. Br.

Albany district, fl. m. April. Cannington, in sandy soil, fl. m. October.

H. ruscifolia, Labill.

A compact shrub of 5-7 feet with erect leafy branches. Lower leaves to 2½ ins. long, all sessile, even to the young shoots.

Mundijong, in sandy gravelly soil, in open forests of *Eucalyptus marginata*, fl. m. January-March.

H. recurva, Meissn.

A shrub or small tree of 10-20 feet with spreading branches. Young shoots and scales of the involucre, minutely pubescent. Leaves to 5 inches long, rigid and glaucous. Flowers greenish-yellow, strongly and sweetly scented.

Yorkrakine, and Kellerberrin, in granite soil, among thickets of *Acacia acuminata* and *Eucalyptus loxophleba*, fl. m. August.

H. multilineata, Meissn.

A small tree of 10-20 feet, with a thick trunk, rough dark grey bark and reddish timber. Adult leaves quite glabrous, with dark-coloured tips. Racemes up to 6 inches long, the flowers either light yellow or deep pink.

Wyalkatchem, Tammin, Yorkrakine, Bungulla, Carrabin and Southern Cross, in yellow sandy soil in thickets, fl. m. August-September.

A narrow-leaved form, with leaves 4-6 inches long, but under ¼ inch wide, occurs at Coolgardie and Westonia. The racemes are much smaller and shorter, and the flowers white. The habit is that of the typical form.

H. laurina, R. Br.

Tambellup, Stirling Range and eastwards to Esperance. A shrub or small tree of 10-25 feet. Perianth red, the style yellowish-white. Fl. m. April-June.

H. cucullata, R. Br.

Stirling Range and Kalgan Plains, fruiting m. March.

The species appears to be confined to the sand plains around the Stirling Range, and the coastal plain to the east. Drummond's locality of "towards Swan River" is misleading.

H. myrtoides, Meissn.

Mogumber and Victoria Plains. Flowers deep pink. A shrub common on the granite hills of the Darling Range in the vicinity of the Moore River, fl. m. July.

H. florida, R. Br.

A densely branched shrub of 4-6 feet with pungently lobed leaves. Near the summit of Mount Toolbrunup, Stirling Range, in scanty soil among shales, fruiting m. April.

H. varia, R. Br.

Attains the proportions of a small tree 10-18 feet high. Flowers white. Common in the Vasse district, in swampy sandy places, fl. m. July.

H. sulcata, R. Br., var. *scoparia,* Benth.

A shrub of 3-6 feet with rigid erect branches. Flowers varying from almost white to pink and purple.

Yellow sandy soil in thickets, Goomalling, Dowering, Wyalkatchem and Nungarin, fl. m. July-August.

H. Lehmanniana, Meissn.

Flowers pale blue. Gnowangerup and Wagin, fl. m. June-August.

H. lissocarpha, R. Br.

3-6 feet high, densely and intricately branched. Flowers white, heavily scented. Kellerberrin and Yorkrakine, in sandy loam with *Acacia acuminata,* fl. m. August-September. "Honey bush."

H. bipinnatifida, R. Br.

Flowers white, suffused with pink. A common shrub in the vicinity of the Swan River, extending over the Darling Range.

Banksia Meissneri, Lehm.

Spikes cylindrical, 1 inch long, flowers yellow.

Collie River, Muja, in sandy swampy soil, fl. m. April.

B. occidentalis, R. Br.

A shrub of 6-15 feet, flowers deep scarlet. Swampy places around Albany, fl. February-March.

B. littoralis, R. Br.

Extends to the Moore River, flowers yellow.

B. verticillata, R. Br.

A tree of 50-60 feet with a diameter of 20-30 inches. Flowers yellow. An inhabitant of the banks of streams in the South-West between the Collie and Kalgan Rivers. Fl. m. October-January.

B. Brownii, Baxter.

I collected this handsome species on the summit of Bluff Knoll in scanty stony soil at an altitude of 3,640 feet. Flowers golden-orange. Here it is a small spreading shrub of 2-4 feet, fl. m. April-May.

B. attenuata, R. Br.

An inhabitant of poor sandy soil.

Watheroo, in arid sandy soil with *Jacksonia eremodendron,* fl. m. January.

B. Solandri, R. Br.

Flowers dull purple. Warrungup Hill and Toolbrunup, Stirling Range, in sandy stony soil, fl. m. October.

B. prostrata, R. Br.

Stems trailing for several feet. Spikes erect, but lying in the soil, orange-red.

Kalgan Plains, and declivities of the Stirling Range, fl. October-April.

B. quercifolia, R. Br.

Flowers scarlet. Sandy swampy places around King George's Sound.

B. marginta, Cav.

Nornalup Inlet, in humid valleys, fl. m. April.

B. coccinea, R. Br.

Common throughout the Stirling Range, fl. m. October.

B. prionötes, Lindl.

A shrub to a tree of 25 feet with a stout trunk and white bark. Extends eastwards to the Tammin Sandplain. It is also fairly common in King's Park, Perth, fl. m. April-May. Flowers orange-yellow, the buds woolly-white.

Hannafordia Kesselli, n. sp.

A small bushy shrub of 2-3½ feet with erect leafy branches, clothed throughout with a dense ferruginous tomentum, which is densest on the underside of the leaves, young shoots and calyces, that of the branches being closer and shorter. Leaves lanceolate, cordate at the base, tapering towards the apex but obtuse, quite entire, flat and thick, stellate tomentose above with a prominent midrib, more ferruginous-tomentose underneath where the veins are more prominent. Peduncles short and thick, leaf-opposed, bearing

two flowers on short pedicels. Bracts none. Bracteoles usually two, close to the calyx, but distinct from it. Calyx campanulate, divided to over two-thirds of its length into narrow-lanceolate acuminate lobes, densely stellate-tomentose and brownish without, glabrous and light green within. Petals oblong, with a concave base, the lamina concave, green, striated with purple lines, the ligula almost linear and recurved. Staminodial-tube deeply divided into 12-15 narrow-linear glabrous filaments, the tube dilated at the base and exceeding the ovary in length. Stamens concealed within the petals, the short filaments attached to the ring of staminodes, near the base of the cup, erect, bearing ovoid-oblong anthers with parallel cells opening outwards, the connective much thickened. Ovary globular or ovoid-globular, sessile thickly beset with stellate hairs, the style simple, short, glabrous and slightly curved, the stigma clavate. Capsule ovoid-globular partially enclosed within the persistent base of the calyx, woody, densely clothed with a thick brown stellate tomentum which wears off with age, the valves acute and splitting down the axis. Seeds glabrous, smooth and brown.

Shrub of 1-1.5 metres in height. Leaves 3.5-4 cm. long, and 1.7 cm. wide; petiole 8 mm. long. Peduncle 3 mm. long, pedicels 1.5 mm. long. Calyx 1.5 cm. long and 6 mm. diameter at the base, the lobes about 1 cm. long. Petals 4 mm. long, the base 1.5 mm. wide. Filaments .5 mm. long; staminodial cup 6 mm. long, including the length of the staminodes; style 2 mm. long. Capsule 1 cm. long, 6 mm. diameter.

Bendering, W.A., in thickets of *Casuarina Huegeliana* and *Acacia acuminata,* in yellow sandy soil, fl. February-June, fruiting m. November. (5th February, 1923, C.A.G.)

The Tpye is No. 1923 of the Forests Department Herbarium.

The new species is dedicated to Mr. S. L. Kessell, Conservator of Forests in Western Australia. It affinity lies in *H. Bissillii,* F. v. M., from which it differs in the longer petiole, smaller calyx, much smaller and differently shaped petals, longer and equal staminodia.

The arrangement of the staminodia is quite different to that of the other known species.

Hypocalymma punicea, n. sp.

An erect slender shrub of 3-5 feet with loose branches, the whole plant glabrous. Branches leafy only at or near the ends. Leaves linear-triquetrous, with a minute recurved point (uncinate) covered with minute oil-glands. Flowers deep pink, large, the petals spreading, solitary on the leafy branchlets on exceedingly short slender pedicles. Bracts none. Bracteole small linear-lanceolate at the base of the calyx. Calyx-tube broad and almost flat, the lobes

orbicular, pink with white scarious margins. Petals orbicular on a slender claw. Stamens numerous in a single row. Ovary superior, attached by the broad base, depressed globular but slightly ridged at the summit, 2-celled with two ovules in each cell, the style slender, glabrous, inserted in a central minute depression; stigma small capitate, yellow.

Plant 1-1.75 metres high. Leaves 1-2.5 cm. long. Pedicles .5 mm. Calyx 3 mm. diameter, lobes 3 mm. long. Petals 8 mm. long.

Bendering, in yellow sandy soil among thickets of low dense shrubs. fl. m. February. (No. 1922, 5th Feb., 1923, C.A.G.)

The new species must be placed in the Section *Eucalymma* of Bentham on account of its 2-celled ovary. It differs from the other members of this section in the style being inserted in a central depression, and not continuous with the summit of the ovary. It has affinity to *H. longifolium* and *H. scariosum*, differing from the former in its solitary pedicellate flowers and shorter leaves, and from the latter in its solitary flowers, which are both pedicellate and larger, and from both in the style.

The Type is No. 1922 of the Forests Department Herbarium.

Melaleuca arenaria, n. sp.

A rigid bushy shrub of 1-3 feet, glabrous except the flowers and the young shoots, which are minutely pubescent. Leaves alternate, obovate or almost orbicular when small. obtuse, narrowed into a short petiole, rigid, spreading, nerveless, or very obscurely one-nerved. Flowers pink. in terminal globular clusters, the rhachis growing out after flowering, few together in a dense head, the rhachis and calyx villous. Calyx-tube campanulate. densely villous in the lower part, the lobes scarious and orbicular. Petals orbicular, scarious, early deciduous. Stamens shortly united in bundles of 3 or 4. Ovules not numerous. Fruiting calyx globular-urceolate, contracted at the top, smooth and flat at the orific with a narrow rim.

Shrub of .3-1 metre in height. Leaves 3 mm. long and 2 mm. wide. Calyx-tube 2 mm. long. Staminal bundles 5.5 mm. long.

Bendering, in arid sandy soil among low stunted shrubs on open plains, fl. m. Oct.-Nov. (No. 1838, 28th Nov., 1922, C.A.G.)

The species comes nearest to *M. polycephala,* Benth., differing in the obtuse, much smaller leaves, the calyx-tube not membranous. From *M. spathulata,* Schau., it differs in the rhachis and calyces not being hirsute, and from both species in the fruits being arranged—not densely packed—in small heads of 2-6.

The Type is No. 1838 of the Forests Department Herbarium.

Jour. Roy. Soc. Western Australia, Vol. IX., Part II., Plate II.

Hannafordia Kesselli, Gardner. A Habit. B Fruits. C Calyx (opened). D Petals and Androecium. E Androecium. F Petal. G Stamen. H Ovary. I Fruit in section.

THE ESSENTIAL OILS OF SOME WESTERN AUSTRALIAN PLANTS.

By L. W. Phillips, B.Sc.

(Abridgment of a thesis approved by the University of Melbourne for the M.Sc. degree.)

Read 8th May, 1923.

This paper describes the essential oils of the following plants: —*Eucalyptus spathulata, E. Campaspe, Agonis flexuosa.*

Part I.

The Essential Oil of Eucalyptus Spathulata (Hooker).

Introductory.

In April, 1922, a sample of crude eucalyptus oil, labelled "E. Uncinata," was supplied to the writer by Mr. H. V. Marr, of Plaimar, Ltd., Perth. It had been distilled at Harrismith, near Narrogin, W.A., by Mr. T. A. Stewart, in March, 1921, and was forwarded to Perth, together with specimens of plant material used. The Forestry Department, W.A., had previously identified some specimens as *E. uncinata* for Mr. Stewart, and it was understood that the leaves and terminal branchlets of the same species had been used in the distillation. The chemical composition of the oil, however, was proved by this investigation to be so different from that reported by Baker and Smith for *E. uncinata*, that a search was made for the plant material which originally accompanied the oil. This was discovered and, together with fresh specimens obtained from Mr. Stewart, was submitted to Mr. C. A. Gardner, botanist to the Forestry Department, for identification. He determined the species as *Eucalyptus spathulata.* This species has two well defined forms—a mallee and a medium sized tree. The former is fairly common on the sandplains of the districts east of the Great Southern Railway, and is rendered conspicuous by its slender stems (4-9 feet) and its small bright leaves. The latter form, known popularly as Swamp Mallet or Swamp Gimlet, occurs in the sandy swamps which exist in the lake country to the east of Narrogin, Wagin, and Katanning. It is a spreading tree of 20-35 feet with a smooth trunk and thin warm red bark. It has not the fluted

trunk of *E. salubris*. The bark of this species contains up to 26 per cent, tannin. It is therefore of some commercial value. There is no record of the essential oil of this species having been previously examined.

Crude Oil.

A steam distillation of leaves and branchlets by Mr. H. V. Marr showed that the yield of crude oil was 1.43 per cent. The oil was a light orange green colour and possessed a very pleasant camphoraceous odour.

Its physical characters were as follows—

Specific Gravity at 15°C	0·9239
Optical Rotation	+ 1°·18
Refractive Index at 20°C	1·4700
Saponification Number	5·45
Saponification Number after acetylation ...	45·16

The oil was soluble in 4 volumes of 70 per cent. alcohol.

The saponification number corresponds to 1.93 per cent. of esters calculated as geranylacetate, $C_{12}H_{20}O_2$, while the acetyl number corresponds to 10.89 per cent. of alcohol calculated for geraniol ($C_{10}H_{18}O$). 65 per cent. of the oil was found to be cineol, determined by the B.P. method with syrupy phosporic acid.

50 c.c. of the oil was fractionated under atmospheric pressure. Below 160deg. a little water and oil came over amounting to 2.5 per cent. This was acid in reaction and reduced Schiff's reagent. The remainder of the oil distilled as follows:—

First Fraction 160° — 165°C	20·4 per cent.
Second Fraction 165° — 172°C	17·4 „
Third Fraction 172° — 192°C	50·3 „
Fourth Fraction 192° — 240°C	6·2 „
Residue calculated by difference ...	3·2 „

The fractions had the following physical constants:—

——	Specific Gravity at 15°C.	Optical Rotation.	Refractive Index at 20°C.
First Fraction	0·9029	+ 7°·96	1·4623
Second Fraction	0·9123	+ 5°·69	1·4628
Third Fraction	0·9249	— 1°·84	1·4667
Fourth Fraction	0·9521	— 4°·61	1·4950

The first fraction was refractionated and 7 c.c. obtained distilling between 157deg. and 160deg. C. It still possessed a faint odour of cineol and was again refractionated, 4 c.c. being obtained distilling between 156deg.-160deg. C. It was dried with calcium chloride, placed in a freezing mixture and cooled hydrogen chloride passed into it when a solid hydrochloride was obtained melting at 126deg.-127deg. C., showing that the terpene is d — a — pinene. No crystalline nitrosite could be obtained from the third fraction, so phellandrene and terpinene are absent. The fourth fraction gave the colour reactions for the sesquiterpene aromadendrene. Bromine added to the solution in glacial acetic acid, formed a crimson colour gradually darkening to violet and then indigo. A drop of concentrated hydrochloric acid gave a similar change. Concentrated sulphuric acid in small quantities produced a bright crimson colour at the junction of the liquids. This changed to a peculiar reddish brown on mixing. Phosphoric acid gave a madder colouration at the junction of the liquids. The presence of the crystallisable phenol, australol, was indicated by the yellow colouration produced by a neutral alcoholic solution of ferric chloride, and the yellow colour of the rectified oil.[a] The negative rotation and reducing properties of the fourth fraction indicated the presence of an aldehyde. This was estimated by shaking the crude oil for six hours with 35 per cent. sodium bisulphite. The absorption corresponded to 2.5 per cent. Baker and Smith use the term aromadendral for the mixed aldehydes usually present in eucalyptus oils, viz., aromadendral, cryptal and cuninal.[b] Penfold has since shown[c] that aldehyde aromadendral is really a mixture of phellandral and cuminal, but it is convenient to retain the term for the mixed aldehydes.

The residue which separated on distillation was brown in colour and had a waxlike appearance. Absolute alcohol dissolved the sesquiterpene and other bodies, leaving a white powder which was recovered by filtration. This was insoluble in ether, xylene and petroleum spirit. It was soluble in chloroform and was precipitated on the addition of alcohol. Its melting point was very high—290° -292° C. An ultimate analysis showed that it was composed of—

Carbon	77.5 per cent.
Hydrogen	9.65 per cent.
Oxygen	12.85 per cent.

corresponding to $C_8H_{12}O$. This compound is apparently identical with the deposit which forms in certain eucalyptus oils on standing for three or four years, and shown by Baker and Smith to be a

(*a*.) Baker and Smith, Research on the Eucalypts (1920), 395–396.
(*b*.) Idem, 61, 98, 134, 383.
(*c*.) Penfold, J. Chem. Soc., 1922, 121, 266.

polymerised body of exceedingly high molecular weight, probably belonging to the neutral resins.[a]

A fresh sample of the crude oil was distilled and all the oil distilling below 190° collected. This had a very faint yellow tinge. Its specific gravity at 15° C. was 0.9191 and its optical rotation 2°.0. It was soluble in five volumes of 70 per cent. alcohol. It contained 72 per cent. cineol determined by the B.P. method. Phellandrene was absent. The rectified oil thus satisfies the requirements of the British Pharmacopœia for a medicinal eucalyptus oil.

Summary.

1. An oil supposed to be distilled from *E. uncinata* was found to have been distilled from a different species, viz., *E. spathulata,* the oil from which had not been previously examined.

2. The principal constituents have been found to be cineol, *d* — *a* — pinene, alcoholic bodies, esters, aromadendrene, aromadendral, and a polymeric body with the composition given by the formula $C_8H_{12}O$. Phellandrene and terpinene are absent.

3. The cineol content is such that when rectified the oil could be used for medicinal purposes.

PART II.

The Essential Oil of Eucalyptus Campaspe (Spencer Moore).

Introduction.

Eucalyptus campaspe occurs on the Eastern Goldfields around Coolgardie, southwards to Norseman, and eastwards along the Great Western Railway for a considerable distance. It is usually a tree of 25-35 feet with a slender trunk, a smooth rich brown thin bark, brown, hard, dense timber and glaucous foliage. Although resembling the true Gimlet (*E. salubris*) in habit, it is readily distinguished by its white powdery branchlets. It occurs in fairly close formation, on red stony soil, and is plentiful in its somewhat restricted habitat. Leaves and terminal branchlets were collected by Mr. C. A. Gardner, Botanist to the Forestry Department, W.A., at Widgemooltha, near Kalgoorlie, on the 1st October, 1922. The material was forwarded to Perth, and through the kindness of Mr. H. V. Marr was distilled at the works of Plaimar, Ltd.

Crude Oil.

The yield of oil was 0.72 per cent. It was yellowish-green in colour and possessed the odour characteristic of the aldehydes of eucalyptus oils together with a secondary odour of cineol. The

(*a*.) Baker and Smith, Research on the Eucalypts (1920), 422.

constituents found to be present were: pinene, cymene, cineol, aromadendral, esters and alcoholic bodies. The crude oil had the following characters:—

Specific gravity at 15° C.	0.9118
Optical Rotation	5°.43
Refractive Index at 20° C.	1.4762

The oil was soluble in 5 volumes of 80 per cent. alcohol. The saponification number for esters and free acid was 8.43. After acetylation, the ester number was 72.13, indicating the presence of a considerable proportion of alcoholic bodies—18.65 per cent. calculated for a $C_{10}H_{18}O$ molecule. The cineol content is very low. It was estimated by the B.P. method with phosphoric acid and found to be about 15 per cent. Phellandrene and terpinene are absent.

Fractional Distillation.

On fractionating the crude oil 1.4 per cent. of volatile aldehydes and acid water came over below 158° C. The remainder distilled as follows:—

1st Fraction—158°-170° C. ..	31.8 per cent.
2nd Fraction—170°-190° C. ..	38.1 per cent.
3rd Fraction—190°-265° C. ..	28.7 per cent.

These fractions were examined with the following results:—

——	Specific Gravity at 15°.	Optical Rotation.	Refractive Index at 20°.
First Fraction	·8844	+ 10°·39	1·4679
Second Fraction	·8977	+ 0°·98	1·4701
Third Fraction	·9405	— 8°·45	1·4958

The terpene present is evidently $d-a-$pinene. This is suggested by the physical properties of the fraction distilling between 158°-170° C. The nitrosochloride was prepared in the manner proposed by Wallach and a fine-grained crystalline precipitate in small quantity obtained. This was separated and dried and found to melt at 101° C. There was not sufficient to recrystallise. The high refractive index of the second fraction indicated the presence of some other constituent and in the absence of terpenes yielding a crystalline nitrosite, cymene was suspected and found to be present in considerable quantity. The second fraction was treated with phosphoric acid and 50 per cent. resorcinol to remove cineol and alcoholic bodies, and

4 c.c. were oxidised by potassium permanganate in the usual way. The hydrated manganese dioxide was filtered and the filtrate evaporated almost to dryness. The sodium salt was successively extracted with alcohol and the solution evaporated to small bulk and water added. The solution was acidified with sulphuric acid and the separated acid crystallised from alcohol. It had a melting point of 155° C. This, together with its method of preparation, indicated *p* oxyisopropyl-benzoic acid, the oxidation product of cymene. The presence of the mixed aromatic aldehydes characteristic of eucalyptus oils, and termed "aromadendral" by Baker and Smith, is indicated by the yellowish-green colour of the second fraction and the reducing properties of the third fraction.

5 c.c. of the crude oil were shaken for 6 hours with a solution of 35 per cent. sodium bisulphite in a flask with graduated neck and the volume of the unabsorbed oil measured. Eight per cent. of the oil was absorbed.

The sesquiterpene present in the third fraction is evidently aromadendrene, as all the characteristic colour reactions of that compound are given.

Summary.

1. The constituents present are: cineol, pinene, cymene, aromadendrene, aromadendral, also esters and alcoholic bodies.

2. No economic use for this oil can be suggested at present.

Part III.

The Essential Oil of Agonis Flexuosa.

Introductory.

Agonis flexuosa is a tree very well known in Western Australia under the name of "Peppermint." A better name, but one not so generally used is the "Willow Myrtle," a name which well describes the graceful pendant branches which give to it its value as an ornamental tree. It is to be found all along the coast of the South-West from North of the Swan River to Augusta and inland along the banks of rivers and streams. In the tuart (*E. gomphocephala*) forest it is present as an undergrowth and has to be cut back annually. It then produces a coppice growth and for this reason the Conservator of Forests, Mr. S. L. Kessell, suggested that its essential oil should be examined with a view to determining its economic value. There was no record in the Forestry Department of a systematic examination of the oil. Von Mueller in his "Extra-tropical plants of Australia" pointed out that it yielded a "yellow

oil with antiseptic properties." Parry[a] had, in 1914, published the results of his investigation of the oil obtained by the distillation of leaves from trees growing in the Botanical Gardens, Melbourne. He showed that the oil contained the following constituents:—Pinene, cymene, cineol, esters, alcohols and a phenol. He stated that aldehydes and aromadendrene were absent and that the cineol content varied from 72 per cent. in the oil from leaves collected in autumn to 62 per cent. from those collected in winter. The results obtained by the writer show that in addition to pinene, cineol, esters, alcoholic bodies and an unidentified phenol, the aldehyde, phellandral and the sesquiterpene, aromadendrene are also present, while evidence of the presence of cynene was not obtained.

Distillation.

Preliminary steam distillations were carried on through June, 1922, in a small still at the Perth Technical School Laboratory, and these showed that the yield of oil varied with the nature of the leaves employed. Mature leaves gave a return of oil of 0.62 per cent., while that from young sucker leaves was 0.84 per cent. It was also found that prolonging the distillation gave a peculiar faecal like odour to the oil. This was traced to be due to a phenolic body. In July, 30 kilogrammes of leaves and terminal branchlets were steam distilled for me at the works of Plaimar, Ltd., and 275 c.c. of oil obtained for examination.

Crude Oil.

The crude oil was yellowish-green in colour and has the camphoraceous odour characteristic of the cineol bearing Eucalyptus oils together with a secondary unpleasant odour due to the phenolic compound present. The oil had the following physical characters:—

Specific Gravity at 15°C	0·9090
Optical Rotation	+ 5°·4
Refractive Index at 20°C	1·4650
Saponification Number	4·49
Acetylation Number	26·12
Solubility in 70 per cent. alcohol ...	Dissolved in 4 volumes.

Fractional Distillation.

The crude oil was rectified under atmospheric pressure. Below 160deg. a little acid water and oil distilled. This had reducing

(a.) R. E. Parry, Proc. Royal Soc., Victoria, XXVI (1914). p. 367.

NOTE.—E. J. Parry, "Chemistry of Essential Oils" (1921), p. 390, in giving a summary of these results attributes the work to R. H. Crozier of Melbourne, and gives as his authority Crozier "Perfumery and Essential Oil Record," IX. (1918), 58.

This reference is an extract from a report by R. H. Crozier, of Melbourne, and published in the South African Journal of Industries, December, 1917, and is a compilation of the results of various investigations into oils of the Eucalypts. R. E. Parry's work is there acknowledged.

properties suggesting volatile aldehydes. There was too little for further examination. The temperatures at which fractions were collected, their volumes and physical properties, are set out in the following table:—

Fraction.	Temperature.	Volume of fraction.	Specific Gravity at 15°C.	Optical Rotation.	Refractive Index at 20°C.
1	Below 160°C	0·8 c.	...	...	...
2	160° — 170°C	20·0 c.c.	0·9010	+ 7°·12	1·4625
3	170° — 186°C	69·2 c.c.	0·9095	+ 2°·46	1·4635
4	186° — 260°C	10·0 c.c.	0·9294	+ 1°·8	1·4813

Terpenes.

Pinene was shown to be present in the second fraction by treating 10 c.c. with 50 per cent. resorcinol and syrupy phosphoric acid to remove cineol and other oxygenated bodies. The oil unacted on was recovered and filtered from cineol phosphate crystals and the nitrosochloride of pinene obtained in the usual way by means of amyl nitrite, glacial acetic acid and hydrochloric acid. Crystallisation was assisted by the addition of alcohol. A copious precipitate was obtained. The crystals were separated, washed with alcohol and dried at 50° C. They were found to melt at 102°-103° C. There was no evidence of the presence of other terpenes. No crystalline nitrosite could be obtained from the second fraction indicating the absence of phellandrene and terpinene.

Cineol.

The presence of cineol is indicated by the strong camphoraceous odour of the crushed leaves together with that from the oil. It was estimated by the British Pharmacopoeia method with syrupy phosphoric acid; 50 c.c. of the crude oil was shaken with an aqueous solution of normal sodium hydroxide; the oil was separated, washed, dried and then rectified to 185° C. The oil which distilled below this temperature was used for the estimation. This rectified oil was colourless and possessed an extremely pleasant odour and had the following physical characters:—

Specific Gravity at 15° C.	0.9086
Optical Activity	6.78°
Refractive Index at 20°	1.4639

This rectified oil was found to contain 67 per cent. cineol, corresponding to 60.3 per cent. in the crude oil. Parry reported for the

March oil, 72 per cent. cineol for the whole oil, and 70 per cent. cineol in fractions. He estimated the cineol by means of the resorcinol method. As resorcinol absorbs not only cineol, but also alcohols, aldehydes and certain other oxygenated bodies (*a*) the result obtained by this method will be too high by an amount equal to the percentage of such substances present in the oil and absorbed. That this is so is shown very clearly by his estimates of cineol in the various fractions obtained by distillation of the crude oil. These results are set out and discussed later.

Aldehyde.

The final fraction gave evidence of reducing properties in reducing Schiff's reagent. On agitating 5 c.c. with sodium bisulphate solution for six hours, there was no crystalline precipitate. The oil was separated and the aqueous solution rendered alkaline and submitted to steam distillation, and 1.262 grams of regenerated oil recovered. This had a pleasant lemon odour, acted strongly on Schiff's reagent and, on treatment with phenyl hydrazine, yielded a hydrazone which, on separating, melted at 121-122° C. There was not sufficient oil to prepare other derivatives, but there can be no doubt that it is phellandral which, according to Penfold, yields a hydrazone melting at 122-123 C., and also forms a soluble sulphonic acid in the presence of sodium bisulphite. There was no evidence of the presence of the aldehydes cryptal, and cuminal usually associated with phellandral in Eucalyptus oils. An estimate of total aldehydes in the crude oil by absorption in sodium bisulphite corresponded to 2.5 per cent.

Phenol.

The phenolic compound was not identified. Its presence is indicated by an unpleasant secondary odour which is lost after treatment with sodium hydroxide solution. The oil used for estimation of the cineol was first shaken with a normal solution of sodium hydroxide and separated. The aqueous solution was rendered acid and extracted with ether. The ether was removed from the extract by evaporation, leaving a yellowish brown oil with a peculiar odour somewhat suggesting creosote. The alcoholic solution of the oil gave with neutral ferric chloride, a dark red colouration. Efforts to obtain crystalline benzoyl and acetyl derivatives were unsuccessful. Owing to the small amount of material available, further tests were impossible.

The Sesquiterpene.

The sesquiterpene aromadendrene was found to be present. The characteristic colour reactions were obtained by dissolving a few

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(*a*.) Baker and Smith, Research on Eucalypts, p. 361.

drops of the fourth fraction in glacial acetic acid. To a portion of this solution bromine was added and a crimson colour gradually changing to indigo was obtained. Concentrated hydrochloric acid added to another portion of the solution developed a pink colour, which darkened to crimson and then changed to indigo. Phosphoric acid was added to the acetic acid solution and a madder colour was obtained at the junction of the liquids. This changed to crimson and became violet on standing. The presence of this constituent is indicative of the close relationship between this genus and that of Eucalyptus.

Esters.

The saponification number was 4.49, indicating the presence of 1.57 per cent. esters having the composition $C_{12}H_{20}O_2$.

Alcohols.

After acetylation the saponification number was found to be 26.12, corresponding to 6.08 per cent. alcohols calculated for an alcohol of the formula $C_{10}H_{18}O$.

Baker and Smith have shown[a] that geranyl acetate can be estimated by saponifying the oil with alcoholic potash for two hours at the temperature of the laboratory, as under these conditions the geranyl acetate present can be completely saponified and the geraniol present in the original oil can in this way be determined. The saponification number of the acetylated oil determined in this way was found to be 11.6, corresponding to 1.98 per cent. geraniol. This shows that at least one other alcohol must be present, and in view of the low optical activity of the third fraction it was thought that there must be an optically active alcohol of dextro rotation present to compensate for the lævo rotatory effect of phellandral which is — 130.6° and terpineol was suspected. A test for the presence of this alcohol was made by taking 2½ c.c. of the oil unacted on by sodium bisulphite. This was dissolved in 2½ c.c. of glacial acetic acid and 2 c.c. of amyl nitrite added. The mixture was cooled in ice and 2 c.c. of hydrochloric acid mixed with 2 c.c. of glacial acetic acid were added drop by drop with continual shaking. When the reaction was completed the nitroso-chloride was precipitated by means of water, separated and recrystallised from methyl alcohol. It had a melting point of 112deg.-113deg. C., thereby confirming the presence of terpineol.

(*a*.) Baker and Smith, "Research on the Eucalypts," p. 368.

Comparison of Results with those of Parry.

The physical characters of the crude oil and the various fractions obtained by Parry and the writer are of the same order as is shown by the following table:—

Physical Characters of oils distilled from leaves of Agonis flexuosa.

Date of collection of plant material	July, 1922	July, 1913	March, 1913
Worker	Phillips	Parry	Parry
Specific Gravity at 15°C	0·9090	0·908	0·900
Optical Rotation	+ 5·4°	+ 4·6°	+ 5·3°
Refraction Index at 20°	1·4650	1·4701	1·4657
Saponification Number	4·49	...	7·5
Saponification Number after acetylation	26·12	...	29·1
Solubility in 70 % Alcohol	Dissolved in 4 volumes	...	Dissolved in 4 volumes
Cineol per cent.	60	62	72

The main differences are in the saponification numbers before and after acetylation which might be due to seasonal variation of esters and alcohols. The agreement in the cineol content is more apparent than real, for, as already stated, Parry estimated cineol not only in the crude oil but also in the various fractions by means of resorcinol. His results for the March oil are given in the following table:—

Cineol content of fractions obtained by absorption with resorcin[a].

Fraction.	Temperature.	Volume of Fraction.	Cineol Content of Fraction.
I.	below 170°	5·5 c.c.	2·7 c.c.
II.	170° — 174°	12·0 c.c.	7·7 c.c.
III.	174° — 178°	13·0 c.c.	9·1 c.c.
IV.	178° — 187°	12·0 c.c.	8·6 c.c.
V.	187° — 227°	5·5 c.c.	6·1 c.c. (4·1)
VI.	above 227°	2·0 c.c.	0·8 c.c.
	Whole oil	50·0 c.c.	35·0 c.c.

(*a*.) Parry, Proc. Royal Soc., Victoria, Vol. XXVI., Pf. 11, p. 370.

There is an obvious error in fraction V, and Parry has informed me verbally that the cineol content should have been given as 4.1 c.c. instead of 6.1 c.c. and the total cineol as 33.0 c.c. As cineol has a boiling point of 176° C., provided the distillation has been carried out carefully, the cineol content of the fractions distilling above

187° C. should be very low, and the reported cineol in fraction V. and VI. is really due to absorption by the resorcinol of alcoholic and other oxygenated bodies. Parry reports 72 per cent. cineol for the whole oil; and 70 per cent. cineol estimated in fractions. Correcting for the error in fraction V., and deducting the absorption above 187° it is obvious that the latter figure should have been given as 56.2 per cent. The estimate of 72 per cent. for the whole oil will also be too high by the ogygenated bodies present, and making the same deduction we get 62.2 per cent. cineol for the March oil determined by resorcinol, which figure agrees fairly well with that obtained by the writer for the July oil. His result of 62 per cent. for the winter oil is subject to a similar criticism, but as the esters and alcohols for this oil were not estimated, no correction can be made. The variation in cineol content, if it does exist as stated by Parry, does not range from 62-72 per cent., but is somewhere in the vicinity of 60 per cent.

Cymene.

The presence of cymene is generally indicated by the high refractive index and low specific gravity of the appropriate fraction in which it is concentrated. In this case the refractive index of the third fraction is comparatively low—1.4635. Parry obtained for the corresponding fraction refractive indices which, when corrected for temperature, were slightly higher, viz., 1.4637 and 1.4645 for the fractions distilling between 174°-178° and 178°-187° C. He removed the cineol from the lower fraction by resorcinol and from the remaining oil obtained p. oxyisopropylbenzoic acid by oxidation with permanganate. The writer was not able to obtain this acid from the corresponding fraction after removal of cineol.

Aldehyde.

Parry reported the absence of an aldehyde. He based this conclusion on the fact that no crystalline compound was formed on shaking the crude oil with sodium bisulphite. As has been shown, the aldehyde phellandral is actually present, and as this forms a soluble suphonic acid with sodium bisulphite solution, his observation is explained.

Probable Uses of the Oil.

(1) *Medicinal.*—Owing to the high percentage of cineol present this oil should have all the therapeutic properties of the medicinal eucalyptus oils and could be used as a substitute for ordinary eucalyptus oil for medicinal purposes. Owing to the unpleasant odour of the phenol, traces of which can be detected in the main cineol fraction, it would be necessary first to remove this constituent before rectification. This would increase the cost of preparation of

the rectified oil, making it doubtful whether it could successfully compete with eucalyptus oils, which are produced very cheaply.

(2) This oil has properties of considerable importance as a flotation oil. Experiments by M. P. Bonnerup, Patent Attorney, and myself with a K and K flotation machine made by the Braun Company at the works of Copper Separation Ltd. have shown it to be remarkably efficient in separating cement copper from the gangue. Experiments in this connection are at present in progress.

Conclusions.

Summary.

1. The essential oil of *Agonis flexuosa* has been shown to contain, in addition to pinene, cineol, esters alcohols and a phenol, the aldehyde phellandral and the sesquiterpene aromadendrene, while the reported presence of cymene was not confirmed. The reported variation in the percentage of cineol present is too great.

2. The cineol content is 60 per cent., and the rectified oil could be used for medicinal purposes.

3. The crude oil can be used for flotation of cement copper.

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